

# Control ENGINEERING

INSTRUMENTATION AND AUTOMATIC CONTROL SYSTEMS

A McGRAW-HILL PUBLICATION

PRICE 50 CENTS

JANUARY 1956

## AN EDITORIAL PREVIEW FOR '56

### COMPONENTS FOR CONTROL

#### SURVEYS OF EXISTING EQUIPMENT

- Data Logging Systems
- Electro-Hydraulics/Slides
- High-Speed Recorders

### EQUIPMENT ENGINEERING

- Computing Circuits
- Pneumatics vs. Hydraulics
- Amplifier Elements

### DESIGN TOOLS FOR CONTROL

#### DYNAMIC RESPONSE TECHNIQUES

four articles on the dynamic analysis of equipment, plant, and complete system

### NONLINEAR FUNDAMENTALS

a series of articles on nonlinear control system design . . with plant examples

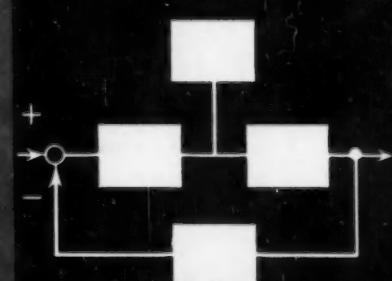
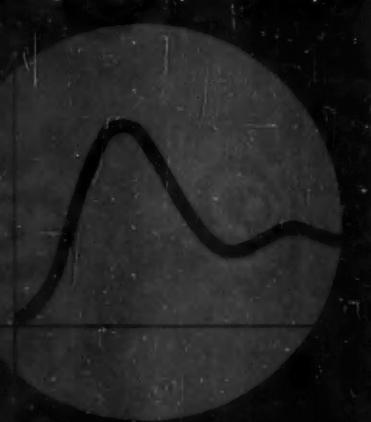
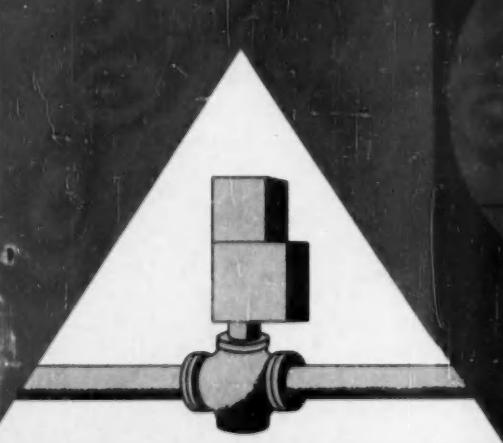
### CONTROL SYSTEMS

#### MACHINE CONTROL

- Automation of Engine Assembly
- Electronic Machine Duplication
- The Control of a Satellite

#### PROCESS CONTROL

a continuing series of articles on the control of unit process operations



## NOW FOR DC OR RESISTANCE INPUT

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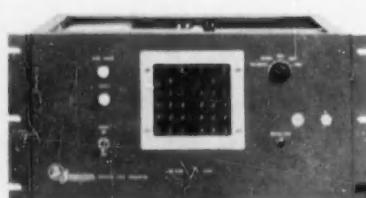
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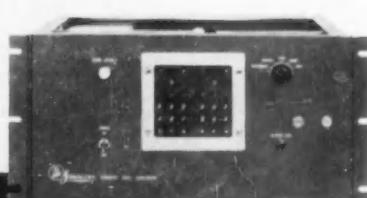
Greater input flexibility For desk or rack mounting



**NEW LIBRASCOPE PUNCHED TAPE CONVERTER**  
Operates from a punched tape reader—Specially designed for Librascope X-Y Plotters—This unit is adaptable to other plotters.

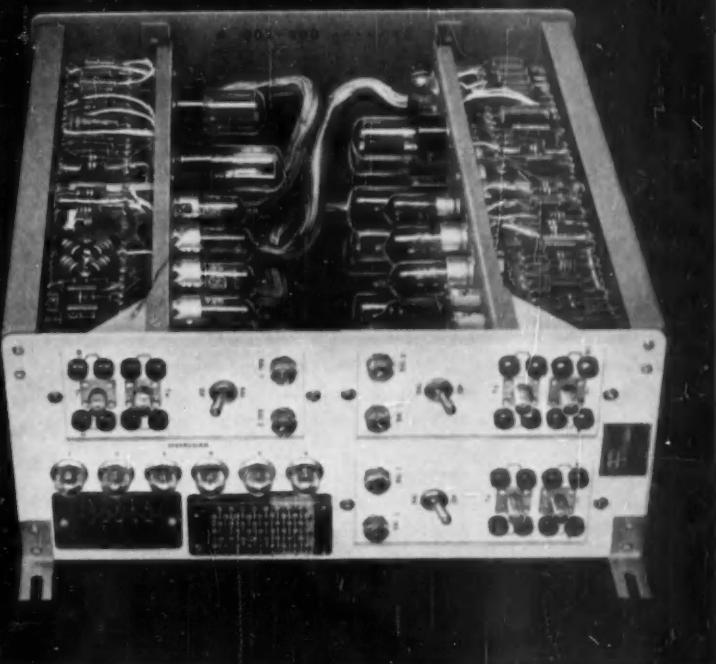


**LIBRASCOPE X-Y DECIMAL KEYBOARD**  
Provides a three-decimal readout for each data with three data input keys featuring short and positive-action self-wiping contacts.



**LIBRASCOPE PUNCHED CARD CONVERTER**  
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of this  
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multiplier?



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A Goodyear Engineering Report, GER-4952, is available which describes the principle of operation of the GEDA electronic multiplier. To obtain your copy and a complete description of the GEDA line, address your inquiry to: Goodyear Aircraft Corporation, Department 931GM, Akron 15, Ohio.

P.S. We are proud to announce the latest addition to the famed GEDA line—the new dual-channel, stabilized noise generator. Of particular value in operational research, precision control and propagation problems, this new unit is one of the 13 versatile analog computing elements that make GEDA the most advanced, most flexible electronic differential analyzer available today.

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connector



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Up to 14 pin  
plug-in



# Control ENGINEERING

JANUARY 1956

INSTRUMENTATION AND AUTOMATIC CONTROL SYSTEMS

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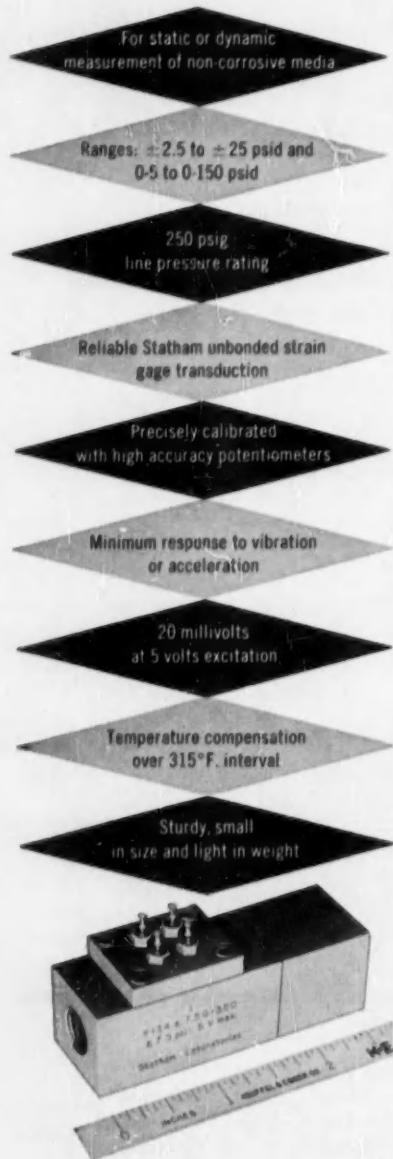
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## differential pressure transducers



Model P134 Pressure Transducers for the measurement of differential pressures are described fully in

Bulletin MPT-134 available upon request.

*Statham*

LABORATORIES

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## SHOP TALK

### MENU PLANNING FOR '56

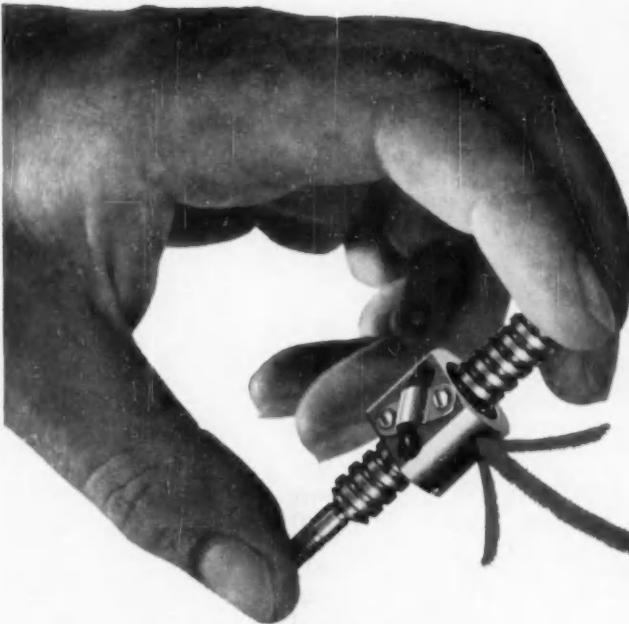
Trudging cross-town on jangling 42nd street one brisk day we got the idea—by most devious means, you'll see—for this month's cover. Somewhere between 7th and 8th avenues, eyes downcast to avoid the lurid distractions, we sniffed the air and smelled roast beef. With this our head jerked up and there we saw . . . THE AUTOMAT. Do control engineers like to eat at the Automat, we mused. Does the idea of push-button selecting a meal (system) from food components satisfy technical as well as gastronomic inclinations? Right then and there we decided to investigate the approach on this month's cover.

Our idea was to make our cover a literary Automat: to display our editorial menu for 1956 in nice sanitary boxes that could be eyed by the hungry subscriber and planned into future hours of epicurean reading. Our master Chef—Art Director Jack Gordon—was all poised with skillet and easel to serve up the viands. But what? Where? And how? We were faced with the formidable problem of classifying control information into courses and dishes and putting it on shelves. Take the individual servings. Would, for example, a steel mill man consider a computer a component or a system? (Is the tomato a vegetable or a fruit?) And how create the courses? Are process control and production control as clearly different as fish and meat? Also, could one make a genus of digital techniques—much like one would group beer and milk into beverages? We pondered . . . and Jack's skillet grew cold, his easel drooped.

### THREE MAIN COURSES, plus aperitifs

Finally, the menu was planned. As the cover shows, we gave Jack three main counters to vend our dishes on—assuming that any hungry control engineer will always require a full meal of components, design tools, and systems stuff. Then we offered the discriminating reader a choice. Would he prefer to sample available components? Or would he prefer to mix his own salad? Would he like a graph or an equation for his main course? Does he enjoy a dessert that is fluid—or discrete? Luckily, the space on a cover is limited. Hence we could only present a brief sample of our editorial fare for 1956. We could not list the many carefully selected aperitifs (PULSE, PERSONALITIES, NEWS, etc.) that will garnish each month's menu. Nor myriad other dishes that are planned (but hard to classify). But we hope that what is listed will whet the appetite and result in hearty reading in the year ahead.

**Solve your critical positioning problems with the**

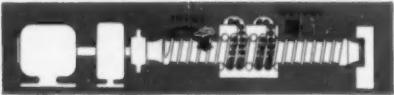


# **SAGINAW ball/bearing SCREW!**

Typical miniature Saginaw b/b Screw specially engineered for electronics application. Length: 3 inches; weight: 2 1/2 ounces. Other units have been built as short as 1 1/2 inches.

**Compact, "flyweight" design . . . hairbreadth precision . . . zero torque . . . "fleapower" operation . . . unprecedented efficiency and dependability make these units ideal for positioning controls in transducers and similar applications**

Operating on a remarkably small amount of power because of its 90% to 95% efficiency, the Saginaw ball/bearing Screw can translate rotary to linear motion (or vice-versa) far more efficiently than any other type of mechanism known. Instead of sliding, mating surfaces



glide on steel balls recirculating in closed-circuit raceways.

In many types of electrical and electronic equipment where space and weight are critical and the positioning of controls must be precise, the Saginaw b/b Screw has proved the perfect solution.

#### **BOTH ROLLED-THREAD AND MACHINE-GROUND TYPES AVAILABLE**

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**FROM 1 1/2 IN. TO 39 1/2 FT. IN LENGTH**

**Saginaw**  
**ball/bearing**  
**Screws & Splines**

#### **SAGINAW DESIGN ADVANTAGES**

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1. FAIL-SAFE MULTIPLE CIRCUITS — no drone or spaced balls. Saves weight, assures more dependability.
2. GOTHIC ARCH GROOVE DESIGN — permits closer lash control, smoother operation, decreased ball stress.
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Average 40 times lower friction coefficient than sliding splines!

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Ball Bearing Screw and Spline Operation  
General Motors Corporation  
Dept 14M, Saginaw, Michigan

Please send detailed information on:

Saginaw b/b Screws       Saginaw b/b Splines

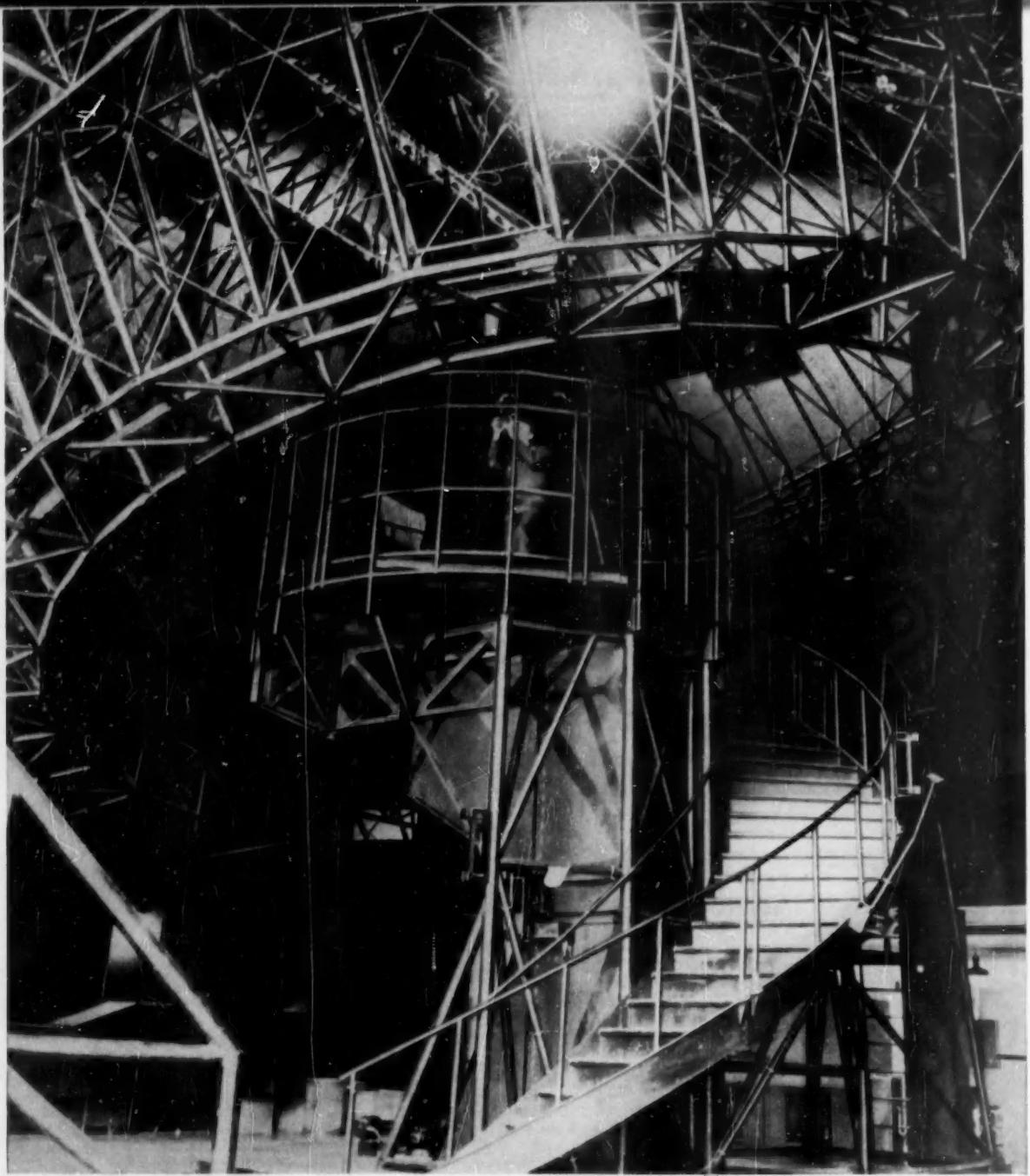
I am interested in their application to

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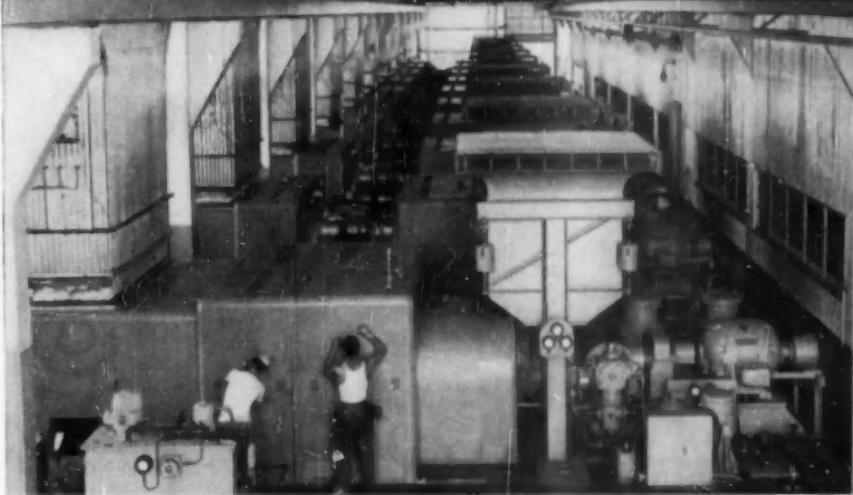
**CELESTIAL NAVIGATION**—Link Aviation's high-speed, high altitude celestial navigation trainer; only such trainer capable of simulating trans-Polar flight. Trains navigators in techniques of guiding planes by the stars.

## Vital Controls

The controls on the world's fastest submarine; the most advanced airborne navigation system known to exist; other similarly advanced military systems and equally advanced industrial equipment and control systems are outstanding examples of the work of the producing companies of General Precision Equipment Corporation. More than a dozen major industries are served by instrumentation and systems designed, developed and produced by GPE Companies.

Ten of the companies in the GPE Group—notably Askania, Kearfott, Librascope and Link Aviation—devote substantial resources to the development and manufacture of instruments, servos and controls. These are used in equipment and systems developed by these companies.

**PROCESS CONTROL**—Askania controls regulate speed of the ten turbines which develop compression to maintain gas suction pressure in Creole Petroleum Corporation's giant, pile-supported oil drilling operation on Lake Maracaibo, Venezuela.

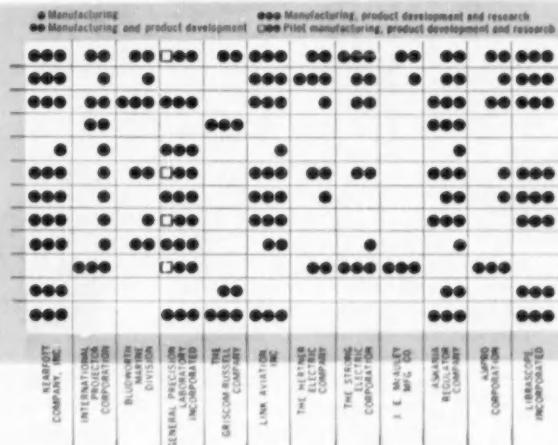


**SUBMARINE OPERATION**—Controls developed and produced by Askania Regulator Company are utilized to govern operation of U. S. Navy's modern Guppy type submarines.



**MISSILE GUIDANCE**—One of the many guided missiles equipped with Kefarott basic gyro reference systems, the B-61 Matador—U. S. Air Force's first successful ground-to-ground tactical weapon.

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themselves, as well as in systems and equipment developed and produced by other manufacturers of advanced technological equipment.

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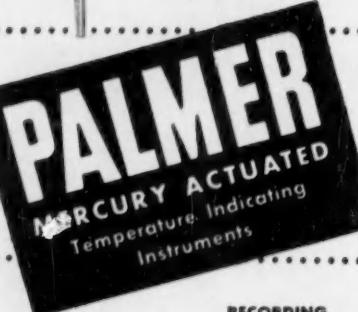
In addition to specialization in its particular products

and fields of technical competence, each of these companies has at its command, as required, the facilities and specialized techniques of the other GPE Companies in their respective fields. Interrelation of their resources is achieved through GPE's basic operating policy, GPE Coordinated Precision Technology. In all areas in which GPE Companies work, this coordination has been responsible for a wide variety of precision equipment of superior design and performance, embodying new, advanced principles.

A brochure relative to the work of the GPE Companies and GPE Coordinated Precision Technology is available. Address your request, or specific inquiries, to: GENERAL PRECISION EQUIPMENT CORPORATION — 92 Gold Street, New York 38, N. Y.

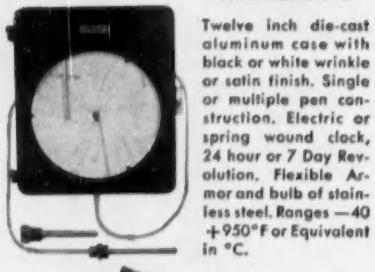
4½" DIAL THERMOMETERS

Made in 3 types to suit any requirements. Rigid stem, wall or flush mounted, 11 inches of scale reading. Interchangeable with standard industrial separable sockets. Stem can be placed at any angle and case can be rotated to any readable position.



RECORDING THERMOMETERS

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## FEEDBACK

Boogered binary . . .

TO THE EDITOR—

I compliment CONTROL ENGINEERING and Mr. Lerner on his article on numbers system which appeared in your Nov. issue. The article did, however, overlook one numbers system which is becoming even more important.

The Gray Code (known also as cyclic binary, non-ambiguous binary, or more simply "boogered binary") is used on digital shaft coders such as the brush commutator type manufactured by Giannini, and the photoelectric type manufactured by Electronic Corp. of America and Baldwin Piano Corp.

Ralph P. Graeber  
RCA Systems Engineering  
Patrick Air Force Base  
Florida

In his letter, Mr. Graeber continued with a description of the Gray Code.

But we received another letter on this subject, from which we extract the details of this important coding procedure. Ed.

. . . and vanishing error

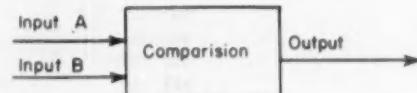
TO THE EDITOR—

In shaft-type analog to digital converters a particular binary code, called variously the Gray, reflected, or cyclical binary code, is often used. As may be seen from a comparison of the two codes (page 9), the Gray code involves a change of only one element in going from one combination to either of the adjacent combinations. But in the normal binary code there may be any number of element changes.

If readout is attempted during a transition between combinations in the normal code, it is possible that only a partial transition has occurred. If this is the case the output code may be far removed from either of the two code

BINARY-GRAY CODE CONVERSION: Mr. Crocker says, "Compare the two inputs . . .

| Input |   | Output |
|-------|---|--------|
| A     | B |        |
| 0     | 0 | 0      |
| 1     | 1 | 0      |
| 0     | 1 | 1      |
| 1     | 0 | 1      |



. . . but be sure to prefix a zero."

Binary to Gray conversion:

Input (binary code)  
Comparison  
Output (Gray code)



Gray to binary conversion:

Input (Gray code)  
Comparison  
Output (binary code)



JANUARY 1956

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combinations involved. Since only one element changes during a transition in the Gray code, the problem of partial transition vanishes with its use.

| Decimal value | Normal binary | Gray binary |
|---------------|---------------|-------------|
| Weighting →   | 8 4 2 1       | 15 7 3 1    |
| 0             | 0 0 0 0       | 0 0 0 0     |
| 1             | 0 0 0 1       | 0 0 0 1     |
| 2             | 0 0 1 0       | 0 0 1 1     |
| 3             | 0 0 1 1       | 0 0 1 0     |
| 4             | 0 1 0 0       | 0 1 1 0     |
| 5             | 0 1 0 1       | 0 1 1 1     |
| 6             | 0 1 1 0       | 0 1 0 1     |
| 7             | 0 1 1 1       | 0 1 0 0     |
| 8             | 1 0 0 0       | 1 1 0 0     |
| 9             | 1 0 0 1       | 1 1 0 1     |
| 10            | 1 0 1 0       | 1 1 1 1     |
| 11            | 1 0 1 1       | 1 1 1 0     |
| 12            | 1 1 0 0       | 1 0 1 0     |
| 13            | 1 1 0 1       | 1 0 1 1     |
| 14            | 1 1 1 0       | 1 0 0 1     |
| 15            | 1 1 1 1       | 1 0 0 0     |

The normal code may be used "as is" in a digital computer, or it may be easily converted to decimal form, either with a matrix or by weighting as shown.

However, the Gray code is not as simple in this respect. Although it may be converted to decimal form with a matrix, it can be converted by weighting only if alternate signs are attached to the weighting.

The most useful procedure seems to be conversion of the Gray code to the normal binary code. This conversion involves a series of comparisons using rules in cuts on page 8.

Prefix a zero to the original number which is to be converted, then proceed. The line extends underneath the two numbers to be compared and the arrow points to the result of the comparison.

These processes may be carried out automatically with "logic" circuits if conversion is necessary as part of a system.

David C. Crocker  
Instrumentation Lab.  
Massachusetts Inst. of Tech.  
Cambridge, Mass.

#### Another way to skin a cat

#### TO THE EDITOR—

Mr. Victor D. Corey's article Calibrate Angular Accelerometers Without Precise Accelerations, in the August 1955 issue of CONTROL ENGINEERING is of direct interest and value to me and to the people with whom I work. Mr. Corey proposed to calibrate angular accelerometers without precise acceleration by milling the output of a calibrated linear accelerometer with the angular accelerometer being tested.

It has occurred to me that Mr. Corey's method might also be valua-

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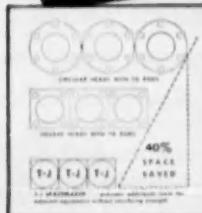
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## FEEDBACK

able for testing rate gyroscopes, merely by rotating the axis of the calibrated linear accelerometer 90 deg so that it is parallel to radius  $r$  of Mr. Cory's Figure 1. The linear accelerometer for testing rate gyros under these conditions must have a functional, rather than a linear, output, but the nulling error would be proportional to the square root of any inherent deficiency in the standard linear accelerometer.

Here's a useful kink; any others? Ed.

### Dynamic analysis proves a point

TO THE EDITOR—

The other day we ran into an interesting comparison between alternate temperature control systems for a distillation column. The alternatives were: (1) the temperature controller resetting a flow controller on the distillation column's reboiler steam supply, and (2) the temperature controller resetting a pressure controller on the steam chest of the reboiler. Briefly, these are the results:

(a) The flow controller cannot hold heat input constant during steam supply pressure changes.

(b) The reboiler presents a time constant of such length that it is the major effect in determining the low ultimate frequency of the temperature control system. The pressure control system has this time constant within its loop, essentially eliminating (by its high gain) the large time constant from consideration. Thus, the ultimate frequency for the overall temperature control system is determined by the next smaller time constant, shifting the operating frequency to a higher range.

We conclude that we should always use the second alternative.

It's always a pleasant experience for these little points to fall into such a sensible pattern that the "best" system can be recommended. I thought that you, too, would be interested in these results even though they are brief.

Bruce E. Powell  
El Sobrante, Cal.

Our readers are always interested in specific examples of theory at work. Tell us more. Ed.

### A group for control education?

TO THE EDITOR—

For the past several years, I have lived in hope that some day the ISA

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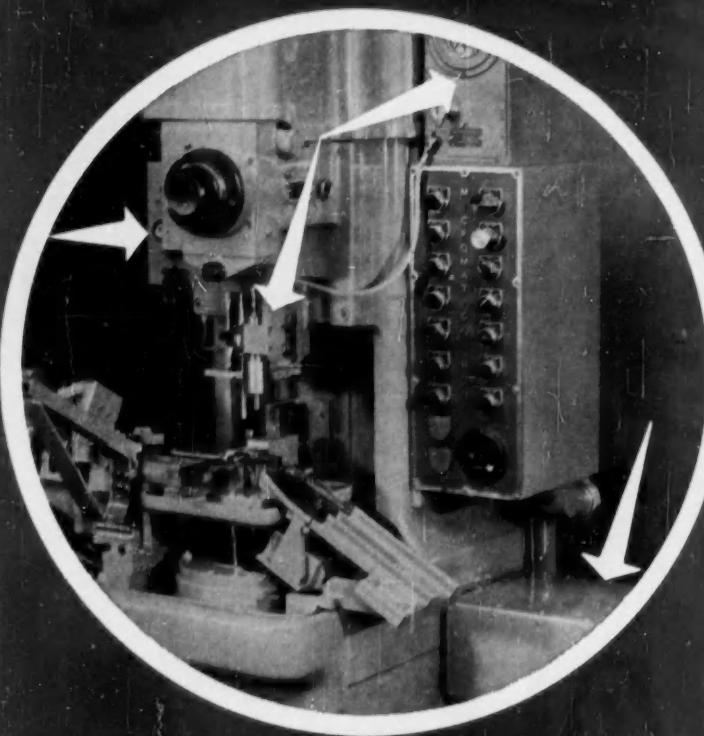
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MACHINE TOOLS GAGES CUTTING TOOLS  
12 CONTROL ENGINEERING

## FEEDBACK

would promote an informal organization of process control engineers within the Society. I thought, perhaps, you might know whether or not such a move is planned and if so, you could give me a list of interested persons.

From an educational standpoint, there has never been a time when an organized effort of process control engineers was needed so badly. This is due to the fact that there is no formal education for process control engineering, which means that a person must secure his formal education in some other phase of engineering and then spend several years serving his "internship" in some well organized industrial process control engineering group, learning to select and apply the proper instruments to control complex processes in our modern industrial processing plants. This situation accounts for the lack of interest in process control engineering by those who have the necessary educational background.

The misapplication of process control instruments being made by improperly trained process control engineers costs industry hundreds of thousands of dollars each year. This conclusion has been forced upon me by many years of association with the problems of process control. In recent years, I have been permitted to assist in solving many process control problems in our own organization and in some of our government's large installations. It is hard to believe, but almost without exception the trouble was caused by the misapplication of process control equipment. It seems to me that the only solution to the problem is for the process control engineers to organize in a group and devote their efforts toward a planned program for recruiting and educating interested persons in control engineering.

G. C. Carroll

Principal Instrument Engineer  
Engineering Services Section  
Olin Mathieson Chemical Corp.  
Baltimore 3, Md.

We suggest that all of our readers who are interested in group activities for process control engineers contact members of ISA's Society Structures and Planning Committee. The committee is currently studying the formation of divisions by job-function and by industry within ISA. Let your interests be known to the committee's chairman, Phil Sprague, Jr., President, Hays Corp., P. O. Box 299, Michigan

City, Indiana. He will be glad to have your comments and to pass them on to the appropriate subcommittee. Ed.

**Leads with chin**

**To the Editor—**

Could you help a faithful reader with some information?

I am looking for a university at which to do post-graduate work on some engineering aspect of digital computers and would thank you for the names of six or eight places in the states that have a reputation in this field.

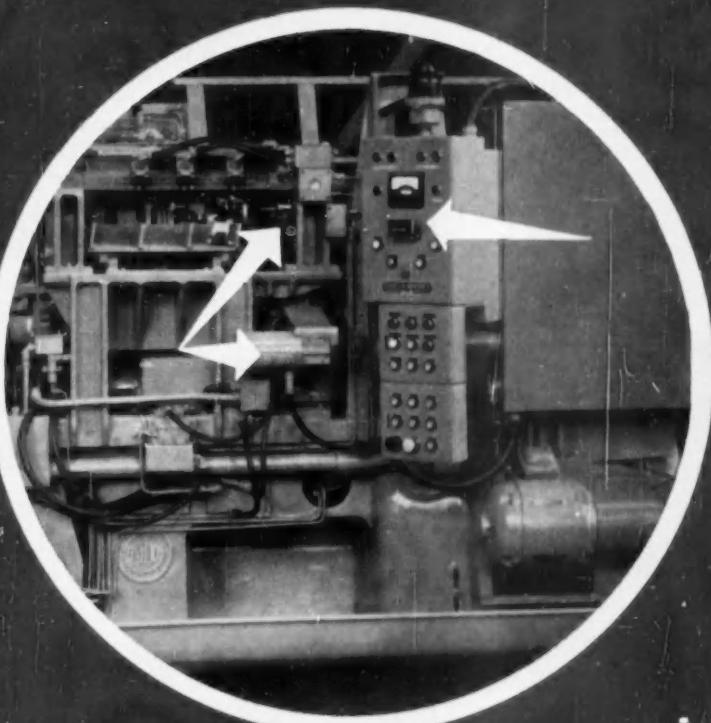
K. Maling  
Toronto 12, Ont.

We're always glad to help one of our readers, faithful or fickle, especially if the information we gather for him is useful to our other readers. We sent Mr. Maling a three-page annotated list of approximately one hundred universities that have computer facilities. The list was prepared by Professor Harry H. Goode, National Chairman, IRE Professional Group on Electronics Computers Student Relations Committee, Willow Run Research Center, Engineering Research Institute, University of Michigan, Willow Run Airport, Ypsilanti, Mich. The Transactions of the IRE Professional Group on Electronic Computers featured the list in its June, '55 issue. Four of the universities listed grant degrees, eight offer assistantships, and 17 handle theses on electronic computers. These facilities present many openings for post-graduate work of the type sought by Mr. Maling and excellent opportunities for extension course training of non-resident engineers.

Our editorial contacts indicate that Mr. Maling's requirements are particularly well met by the following:

- University of Michigan (same address as Professor Goode's)
- MIT Digital Computer Lab, Cambridge 39, Mass.; contact Dr. Jay W. Forrester
- Harvard University Computer Lab, Cambridge, Mass.; contact Dr. Howard H. Aiken
- University of Pennsylvania, Moore School of Engineering, Philadelphia, Pa.; contact Dr. M. Rubinoff
- University of Illinois, Urbana, Ill.; contact Dr. James E. Robertson
- Purdue University, Lafayette, Ind.; contact Dr. A. Perlis
- University of California, Berkeley, Calif.; contact Professor P. L. Morton

Good hunting. Ed.



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Similarly, work has been done in the last two years by this company on systems problems of non-military clients from such diverse fields as manufacturing, banking, transportation and public utility. The results strongly support the conclusion that many of the difficult problems in automation that face business and industry today can be economically solved by teams that include a breadth of technical and non-technical competence which permits them to conduct a highly objective, scientific analysis of a client's operations and requirements.

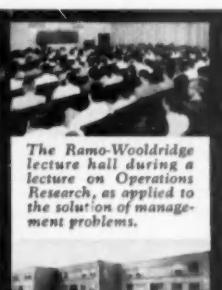
One important advantage to the client of such a broad and objective approach to his problems is the possibility of recommendations that realistic operational needs can be met without the necessity for investment in any additional machines or equipment. Nevertheless, the technical strength of The Ramo-Wooldridge Corporation, provided by its hundreds of scientists and engineers, is such that it can also undertake successfully the development of entirely new equipment and techniques, if required. As an example, major programs are currently under way on the development of an advanced type of digital computer and control system, and on the automation of large-scale data processing activities.

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A  
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# JOHN R. RAGAZZINI raises systems and students

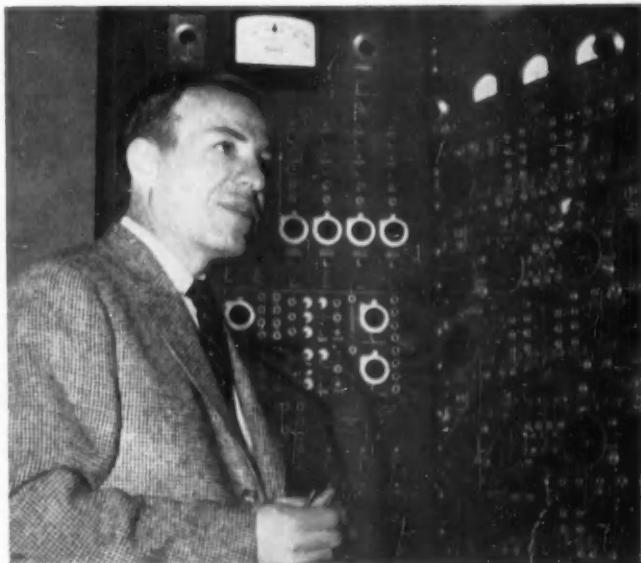
Teaching graduate courses, heading Columbia's Electrical Engineering Dept., directing an important control research project, and acting as consultant to four large firms is surely too big a load for one man. But it doesn't seem to faze Prof. John R. Ragazzini. Visitors to his simple and immaculate office find an amiable and soft-spoken fellow who looks quite a bit younger than his 43 years. "This isn't the office you'll usually find me in," he admits with a smile, "I have another one that I hide in." But it's well known that students with problems have no difficulty finding his hideaway.

Professor Ragazzini was born in Manhattan's Greenwich Village in 1904 and attended grammar school in an area not overburdened with model citizens. "I think that there are only three of us from my grammar school graduating class that managed to stay out of jail," he remarks with a grin. However, a good technical high school prepared him for CCNY, where he made Phi Beta Kappa while going for his BS. An EE degree followed in 1932.

## No jobs—no problem

"There was no problem getting a job those days," he says, "there just weren't any." But he was fortunate enough to become an Engineering Assistant for New York City and in 1935 a part-time instructor at CCNY while beginning graduate work at Columbia. He began a complete "re-education" (which he felt advances in electronics demanded) including enough non-technical courses to earn an MA in 1938. Soon after receiving his PhD from Columbia in 1941 (his thesis was on the rectification of noise) he became an instructor there.

With the war Ragazzini went to MIT for a brief course in microwaves, which he then taught to military and industrial personnel at Columbia for the duration. In '44 he directed construction of an electronic analog computer to analyze equations associated with bombing and gunnery. This work led to the completion of a system, including simulated airplane controls, for analyzing aircraft and pilot performance in following moving targets. Part of this development was a simulator of a human being in a tracking situation (based on measured transfer functions). When the School of Engineering terminated military research contracts in 1945, the professor turned from his computer project to become a con-

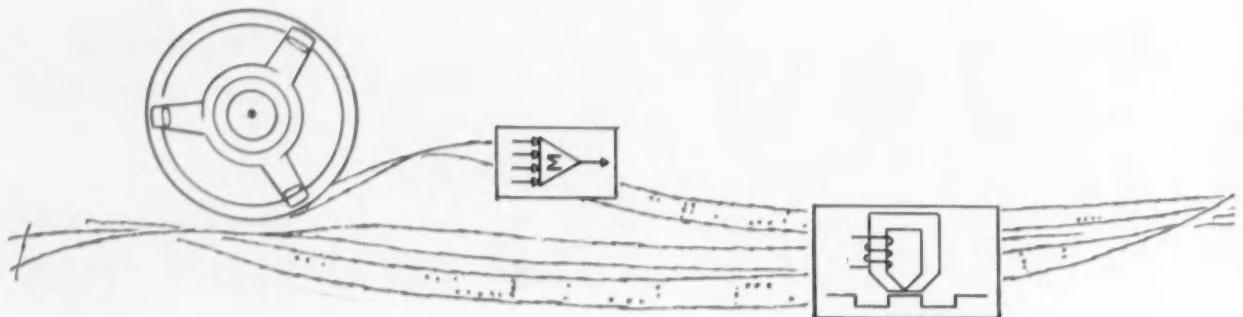


Dr. Ragazzini takes pride in the sampled-data controller his students developed—see *CtE*, September 1955, p. 107.

trol consultant and do research, mainly in guided missiles.

When the school reactivated research for the armed services in 1950, Professor Ragazzini started the Electronics Research Laboratories, which now handle a yearly \$1 million worth of research in various phases of radar digital and analog computers and control. Interest in obtaining control data from the sweeps of radar antennas led him into pioneer studies of sampled-data control. His recent activity in this area includes considerable work in industrial processes. Not long ago he resigned as director of ERL in order to personally run one of its basic projects in sampled-data control systems. And a year ago he instituted the Control Systems Lab and took over the EE Dept., now 500 students strong.

Ragazzini, a past director of IRE and vice-chairman of AIEE's Feedback Controls Committee, commutes each summer to the Connecticut shore and to his wife, son 9, and daughter 7. Today his favorite other-than-work interests are marine sports, but some day, he says, he hopes to be occupied with a sports car.



## The boy

Byron Ledgerwood was born, raised and still lives in Brooklyn, N. Y. On the basis of his accomplishments, you'd hardly believe that he is still on the sunny side of 35. Byron holds a BME from Cooper Union and has completed course credits toward his Masters Degree at Polytechnic Institute, majoring in instrumentation and control.

With the war on, Byron joined the "black gang" as marine engineer in the Maritime Service in 1943. After four years of sailing, and bomb attacks, Byron ended up as Lt. Commander with a Chief Engineer's Marine Steam License.

After a year and a half with General Electric testing turbine, generator and heavy equipment installations, Byron spent three years with General Regulator. As Project Engineer he was responsible for proposals, design, purchasing, manufacture, installation and testing for various electrical, electronic and hydraulic control systems.

Byron's McGraw-Hill experience began in November 1951 when he became editorial assistant on *Product Engineering*, covering electronic, hydraulic and pneumatic control fields. His work in editing the pilot issue of *Control Engineering* resulted in his appointment to the job

of Associate Editor of that publication.

Covering an industry that is fast becoming an integral part of all industry keeps Byron hopping from coast to coast calling on equipment manufacturers and visiting plants where control equipment is in use. As if this weren't enough, he is editing two series of articles on digital computing equipment. These will eventually be published in book form, as will two other books which he is co-authoring.

Byron Ledgerwood is a Registered Professional Engineer in New York State. He holds active memberships in the American Society of Mechanical Engineers, American Institute of Electrical Engineers, and National Society of Professional Engineers, and is frequently asked to speak before these and other engineering societies.

Mr. Ledgerwood's experience, knowledge of his job, and ability to serve his readers, is typical of McGraw-Hill editors. They're specialists. They know their fields. They live with the problems of the men—within these fields—who look to them for accurate reporting of news that is vital to their industry. That is why every McGraw-Hill publication provides and maintains an alert, interested audience for the advertiser's sales messages.



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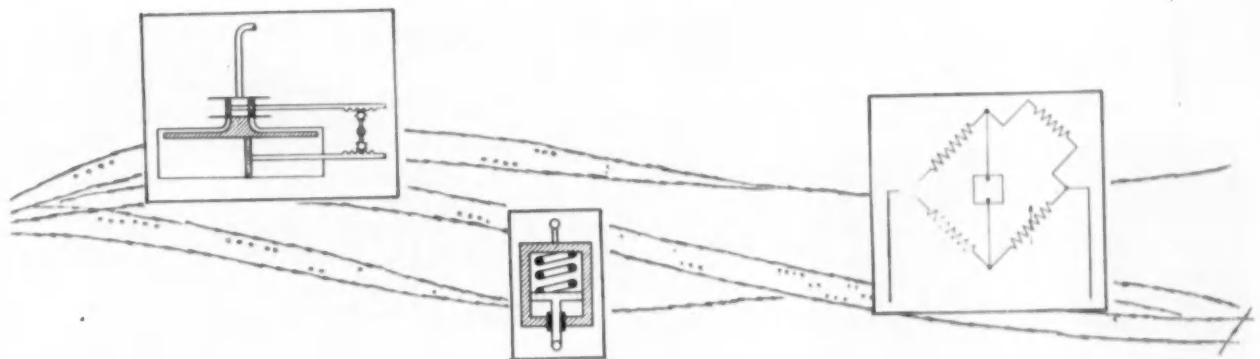
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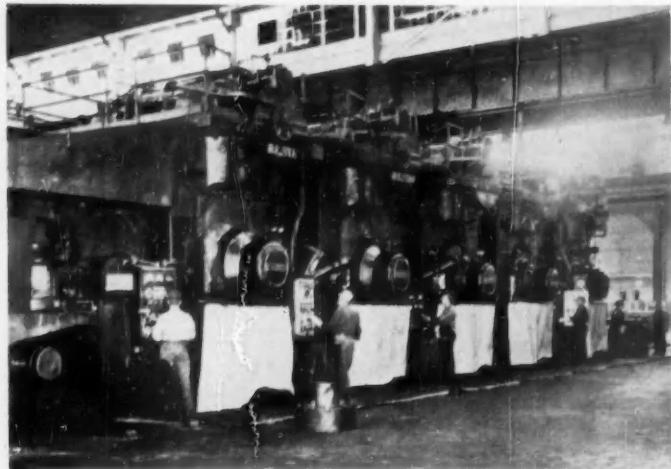
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# from Brooklyn



## WHAT'S NEW



Strip steel whipping through the five roll stands of this tandem mill at 4,000 ft per min is gaged by x-ray indicator-controllers (left) and is automatically held within 0.5 mil tolerances. But there's more to this story of how . . .

## Feedback Control Tames Steel Strip Milling

PITTSBURGH, PA., Nov. 10, 1955—Sheer size and productivity of the process alone make the automatic control of a tandem cold reduction steel mill a major milestone. But General Electric and U. S. Steel in their combined effort at the latter's Irvin Works near Pittsburgh have added at least four "extras" for the feedback hall of fame:

- a system design based on a complete dynamic analysis of the process
- dual x-ray gaging both on incoming and outgoing sheet from the mill
- a combination of screwdown and speed control on the reduction rolls
- exclusive use of transistors and magnetic amplifiers in the system

According to G-E engineers, development of the system got its start in Schenectady a few years ago when they resolved to feed the basic industrial problem—how to automatically hold strip steel tolerances—into an electronic differential analyzer. As the real problem unfurled the analysis started to include not only all electrical constants, but mechanical constants such as roll pressure and interstand tension as well as the ability of the basic drive system to perform minor ironing out of incoming gage variations. With U. S. Steel cooperation, data on real time operation was brought in. Ultimately, when the system was designed it was based on an

authentic dynamic analysis of the reduction process—a pioneer work in itself. The system was then built by G-E's Industry Control and X-Ray Depts.

### Preventive Medicine

G-E's X-Ray Dept.—well up on medical lore—suggested preventive diagnosis as an improvement in the gaging system. For several years it had been customary to use an x-ray thickness gage between the last stand and winding reel of the mill to get an indication of finished strip thickness for manual control. Since it was generally agreed that the main reason for variation was the lack of uniformity in incoming strip, why rely on a "post-mortem" measurement? The engineers suggested an additional gage in an early stage of the mill and possible control therefrom.

In the analysis it was discovered that variations in incoming strip could be substantially reduced through control of stand 1 roll opening and roll speed. After this first pass, further cold reducing renders the steel strip more brittle and susceptible to breakage, thus cuts down the possible range of control in later stands. Hence the additional gage was located between stands 1 and 2.

Measurement established, the automatic control system that evolved

consisted of two portions: A coarse regulation of screwdown motors on stand 1, based on first reduction in thickness, and a vernier control of the drive motor speed on the last stand, based on outgoing strip thickness.

Error signal for the coarse regulation of stand 1 is produced by an x-ray source below the emerging strip and a detector suspended above. When the steel deviates in thickness this signal activates a transistorized discriminator which observes the direction of error and its magnitude. A polarized dc signal is then passed into an on-off time circuit containing magnetic amplifiers. On-timing is a function of the deviation signal magnitude: if steel from stand 1 is 0.5 mil off gage, the screwdown motors will run a shorter time than when the steel is off 0.7 mil.

Besides variable time operation of screwdown motors on stand 1, a check interval is introduced between timed control pulses to allow the strip to pass from rolls to gage so that the correction is "observed". Since strip speed can vary over a wide range, this off-timing interval changes inversely with operating speed of the mill.

### Functions for Mill Peccadillos

Several auxiliary functions had to be integrated into the coarse control to match it to mill characteristics.

For one thing, the major part of off-grade steel supplied to such a mill is usually off-grade toward the head and tail ends of the strip. This requires a "screw-reset" function which returns the screws to a normal position at the end of a coil. A "screw departure" indicator continuously advises the operator of the deviation from normal position. Also, automatic "screw departure limit" circuits prevent the rolls from assuming positions which will overload the drive motors or cause excess slippage. When these circuits act, an alarm light tells the operator that his control is off automatic operation. Still another safety circuit—the "regulator inspector"—will make the control system inoperative if it does not reduce thickness error during a preselected time period. And, again, the operator is notified by a signal light.

### The Final Reckoning

The final control of strip thickness is achieved by automatic regulation of stand 5 speed and of the strip tension between stands 4 and 5. In

this last stand the mill motor gets its power from a common source which also supplies power to the other stands of the drive. The motor field has a current regulator consisting of an exciter and an amplidyne, with both coarse and vernier rheostats controlling the excitation. Hence the speed of the fifth stand can be controlled relative to previous stand motor speeds and thus adjust outgoing steel thickness by varying tension between it and stand 4.

Once again, an x-ray gage measures the finished strip and originates an error signal that is judged for direction and magnitude by a transistor discriminator. This time the polarized signal is increased by a transistorized amplifier to a power level suitable for the field current regulator of the motor.

In operation, the coarse and vernier setting of the motor-field current regulator of the gage system are set to desired output thickness. Control then operates over a range of plus or minus 5 per cent speed. Changing the speed of stand 5 relative to stand

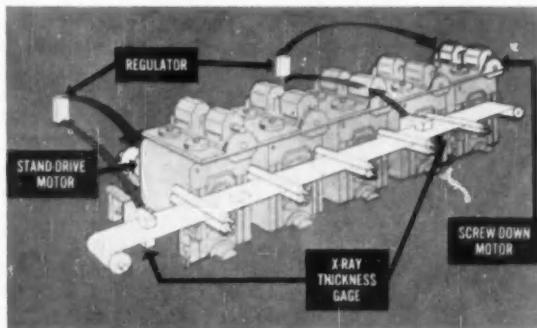
4 changes the draft and tension on the strip between the two stands to effectively control the thickness of the delivered steel.

Special auxiliary functions were also necessary in the vernier control system. Since the regulator range is limited to prevent looping or breakage of the strip, the system automatically is placed on manual when this range is exceeded and the operator warned of the fact by signal light. A "regulator inspector" function also operates at this stage of the system.

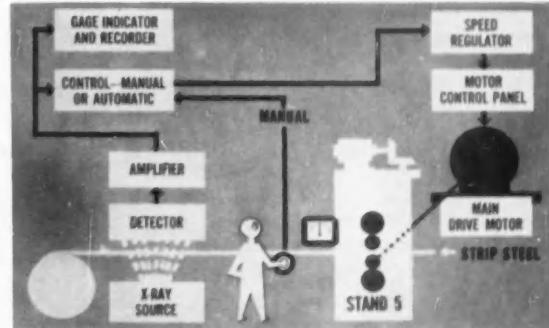
### A Team of Nine Transistors

Perhaps the most newsworthy aspect of the new regulating system is its complete reliance on transistor and magnetic-amplifier techniques in circuits and components. Only nine transistors are actually required, but G-E's Iron and Steel Manager Bill Miller claims, "This is one of the first instances where transistors have been used to control main drives of 3,000 horsepower. We are confident that this is the system of the future."

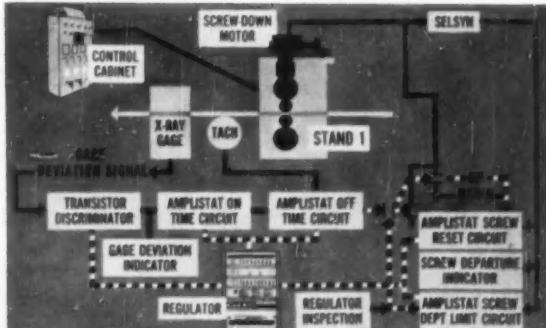
## FOUR CLOSE-UPS OF MILL CONTROL FUNCTIONS



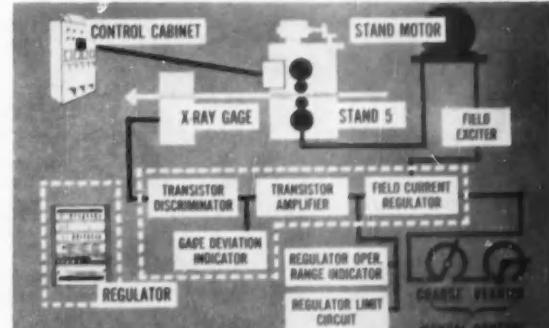
THE MILL consists of five roll stands and a tension reel arranged in a continuous line. One main drive motor powers all stands.



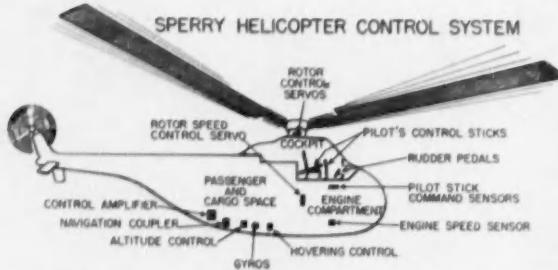
X-RAY GAGES are located with source below the steel strip and detector above. Error signals due to deviation actuate the regulating system.



COARSE CONTROL is effected by automatic positioning of the rolls on stand 1. This stabilizes the thickness of incoming steel to the mill.



VERNIER CONTROL is accomplished by regulating the speed of stand 5 relative to stand 4. The varied tension changes strip thickness.



**TRANSISTORS IN A WHIRLYBIRD, TOO . . .**  
 Sperry Gyroscope's new miniature, fail-safe, flight control system for helicopters includes automatic trim devices, altitude and speed controls—yet weighs only 60 lb. It's all due to transistorized module design and neat little linkages like the force sensor being pointed at in the test set-up. The system permits unmanned cargo operation.



## CONTROL CONCLAVES

### Chicago, Nov. 14-17

This was a busy week in Chicago for a visiting control engineer. If he happened to belong to ASME he was there for the Diamond Jubilee annual meeting and lost in a mass of 4,500 loyal conventioneers. But he found his control kin—he judged there were several hundred of them—at three excellent IRD sessions. The IRD papers this year were concerned with control valves, and our visitor reports good content and keen interest—particularly in papers given by Gorrie and Gantz on Design Limitations and Shearer on Nonlinear Characteristics. The highlight, however, was the 16-man panel of speakers at the end of the program which jangled and parried with questions raised by the sessions. Leaving the sessions our engineer stretched his legs at what he felt was a rather lackadaisical Power Show in the Chicago Coliseum. "Too small, too gloomy, too dismally remote," he reported.

A brighter, more specific show beckoned the control engineer to the Lake Shore's Navy Pier during this same week. There he became one of 10,000 attendees at Richard Rimbach's Second Automation Exposition. Filling about half the space of the vast pier, the booths' contents ranged from a large flock of counting and digital devices, through three big automatic logging systems, to industrial timers, relays, and components for what our man called "Detroit automation".

The visitors, he thought, were also mainly out of the production engineering mold. But they were obviously good men and there to seriously look. Try as he might, he could not, however, find one central theme that characterized the show.

Early in this busy week our Chicago visitor made a special point to subway down to the Shoreland Hotel and the University of Chicago's two-day session on "Automation for Senior Officers". Here, while the papers were impressive (mainly about automation from a planning and policy standpoint) he was more impressed with the 200 top executives who took two precious days and paid the \$150 fee to get this academically-organized briefing. "The average annual income of the people there," he estimated, "was about \$20,000. Add that up and I was sitting amidst a group representing about \$2 million in annual salary. What was I doing there?"

### Los Angeles, Oct. 28

On this day our West Coast reporter joined a group of 300 in the Gold Room of the Ambassador Hotel to take in the 6th Annual Systems and Procedures Conference. This year the accent was on electronic data processing and its meaning to systems-minded management. Dr. Gene Grabbe, CONTROL ENGINEERING's West Coast consulting editor, keynoted the technical part of the program with a graphic rundown of the capabilities of the new technology. He cited experience with a large scale computer in his own company, the Ramo-Wooldridge Corp.

"Our productive machine time," said Gene, "averages better than 90 per cent of a 40 hour week. This is equivalent to having 25,000 operators with desk calculators working for 40 hours." Even factory-expanding Ramo-Wooldridge, Gene tell us, could hardly stick such a staff vertically under its roof—much less in a normal maze of floor-bound desks. Dr. Grabbe predicted that the major future for computers "clearly lies in the interest and intent of business operations."

### New York, Oct. 20-21

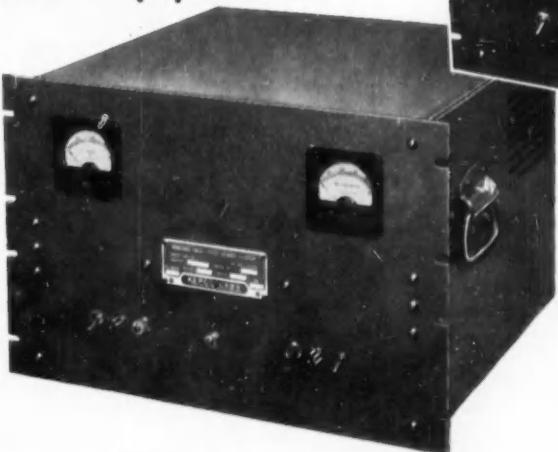
Our visiting control engineer also managed to nestle himself among the several hundred people from industry, government, and schools who attended the Second National Meeting of The Institute of the Management Sciences on two bright October days in Gotham. TIMS is devoted to promoting Operations Research and stresses the application of mathematical and scientific techniques to industrial problems—not to be confused with ORSA (Operations Research Society of America) which concentrates more on military problems. The sessions, he reports, covered a wide area. Gil Dantzig of the Rand Corp., Abe Charnes of Purdue, and W. W. Cooper of the Carnegie Institute discussed various extensions of linear programming, which they played a large part in originating. Other papers: Kircher of the University of California on the use of computers in management; Lieberman of Litton Industries on a mathematical model for

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**RIPPLE:** Less than 3 mv. rms.

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| Model | Volts   | 6.3V AC     | Rack Mount |         |     | Price |
|-------|---------|-------------|------------|---------|-----|-------|
|       |         |             | W          | H       | D   |       |
| KR16  | 0-150   | Each supply | 19"        | 12 1/4" | 17" | \$625 |
| KR17  | 100-200 | has two     | 19"        | 12 1/4" | 17" | \$625 |
| KR18  | 195-325 | 15 Amp.     | 19"        | 12 1/4" | 17" | \$695 |
| KR19  | 295-405 | outputs     | 19"        | 12 1/4" | 17" | \$695 |

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# SANDERS Model 2 Phase Comparator



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modulator,  
demodulator  
or switch

This compact, rugged comparator is hermetically sealed in an inert gas and packaged for mounting in a standard octal socket. Two full-wave bridge rectifiers are used to obtain a high degree of stability and balance.

As phase sensitive comparators, these units can be used to measure the amplitude or phase of an input signal with respect to a reference signal. As demodulators, DC output can be obtained either single-ended or push-pull with respect to ground. Suitable for all military applications.

#### SPECIFICATIONS

**Frequency Response:** 0 to 5000 CPS; **Max. Reference Voltage:** 120V. RMS; **Max. Output Voltage:**  $\pm$  50V. DC; **Dynamic Range:** 46 db; **Load:** Max. 200K ohms, — Min. 20K ohms; **Input Impedance:** Approx. 200K ohms with 200K ohms load and 1:1 transformer. **Size:** 1" dia. x 3"; **Weight:** 2 ozs.

Write for data sheets to Dept. CE1



## WHAT'S NEW

business systems, Ackoff of Case on forecasting. Our reporter concludes, "The scope of the 30 papers was impressive, but sometimes left the listener doubtful as to the connection between the theoretical methods which have been developed and the practical steps which have actually been taken. As one of the speakers, Professor Kircher, observed, it may be that the usefulness of operations research has been due more to the influx of scientifically trained men into management fields than to the actual use of complicated mathematical techniques in solving managerial problems."

**Boston, Nov. 7-9**

Up in the scholarly clime of Back Bay our peripatetic control engineer spent a vigorous three days listening to 19 papers on the use of "computers in business and industrial systems" at the fifth annual Eastern Joint Computer Conference sponsored by AIEE, IRE, and ACM. About 1,000, he reports, jammed the ballroom and meeting rooms of the Statler Hotel—"keen, high-level people from an amazing variety of industries and businesses". The papers were very practical and obviously aimed at prospective users of digital equipment. One good example: a rather lively (rather slanted, too) discussion on the special purpose vs. general purpose computing system. But our man reports this general audience criticism: "There was too much stress on the immediate cost benefits of computers and not enough on the management decision function with its benefits."

## CONCLAVES TO COME

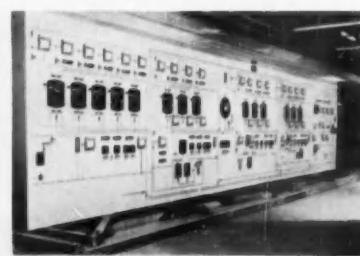
**Princeton, Dec. 29-30**

This year the Industrial and Engi-

neering Chemistry Div. of the American Chemical Society will direct its Christmas Symposium to "Transient Chemical Process Behavior and Control". A good share of the interesting program will be devoted to the new tools of synthesis and dynamic analysis of process and plant and CtE editors Bill Vannah and Lloyd Slater will try to project the crusading zeal of their magazine into the opening address, "Process Control Enters a New Era". Besides this editorial-type keynote there will be some solid contributions from people out in the plants and by pioneering systems engineers from the instrument companies (i.e., Berger and Short of Phillips Petroleum on control characteristics of a pentane fractionator; Franks and Worley of Brown Instruments on quantitative analysis of cascade control). With at least two editors in attendance, our February issue will be sure to carry a full report on the ground that will be covered.

**Heidelberg, Sept. 24-28, 1956**

Professor Thomas J. Higgins, our prolific book reviewer at the University of Wisconsin, writes that a very soundly conceived German symposium on the "Value and Theory in Applications of Control Engineering" will take place next fall at the New University of Heidelberg. The program is subdivided into four main sections: 1) Concept of Theory—its Value and Efficiency; 2) Application and Limits of Elementary Procedures; 3) Mathematical Methods for Solving Control Problems; 4) The Outlook. Those due for a trip to Europe—or verging on a good paper that would fit this program scope—should write to Dr. Otto Grebe, Verband Deutscher Elektrotechniker e.V., Osthafenplatz 6, Frankfort on Main, Germany.



**MONSANTO GETS MAMMOTH ONE-PIECE PANEL** This five-ton, 33-ft-long unit, said to be the largest demineralization control panel ever built, made the trip from Texas City in one crate by truck and sea train. Bogue Electric Co. constructed it in only five months.

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REGULATED
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STABLVOLT TYPE A

## DESCRIPTION

STABLVOLT D. C. power supplies are dual magnetic, precision regulated units providing reliable, maintenance-free operation for industrial, laboratory and original equipment applications.

STABLVOLT's precision regulation with ultra high speed response is attained by utilizing new high performance Flux Oscillators in connection with high gain magnetic amplifiers...thereby eliminating vacuum tubes, mechanical references and other delicate elements.

STABLVOLT's short circuit proof characteristics are achieved by using only static magnetic circuitry. When short circuited, line current is automatically limited and power supply protected from internal damage. Normal operation is resumed automatically, without resetting switches or replacing fuses...thus eliminating downtime and insuring maintenance-free operation.

## SPECIFICATIONS

### TYPE A: 200 WATTS OUTPUT

| MODEL      | DC OUTPUT RANGE<br>VOLTS | AMPERES |
|------------|--------------------------|---------|
| MR-6-5     | 5-7.5                    | 0.3     |
| MR-6-20    | 4-8                      | 0.30    |
| MR-12-10   | 6-15                     | 0.15    |
| MR-28-5    | 16-32                    | 0.75    |
| MR-150-1   | 130-175                  | 0.1     |
| MR-300-0.5 | 270-330                  | 0.05    |

### TYPE A: 1000 WATTS OUTPUT

| MODEL     | DC OUTPUT RANGE<br>VOLTS | AMPERES |
|-----------|--------------------------|---------|
| MR-532-15 | 5-32                     | 0.15    |
| MR-6-100  | 4-8                      | 0.120   |
| MR-12-50  | 6-15                     | 0.70    |
| MR-28-20  | 16-32                    | 0.30    |
| MR-150-5  | 135-175                  | 0.5     |
| MR-300-3  | 270-330                  | 0.3     |

\* Models conform to slightly modified specifications.

### STATIC REGULATION:

±0.2% for ±10% line voltage change  
±0.2% for ±10% line frequency change

±0.2% from 10% to full load current

RIPPLE: 0.2% RMS at full load

6 Volt models have 1% ripple

AC INPUT: 95-135V, 1 phase, 50 to 60 cps

OVERLOAD: Power Supplies are conservatively rated; can be operated continuously at 150% overload current.

SHORT CIRCUIT CURRENT: 200% of rated load current.

### DYNAMIC REGULATION AND RESPONSE TIME:

±2% for ±10% line voltage transient

Response Time: 50 milliseconds

±3% for ±10% load current transient

Response Time: Max. 100 milliseconds under most severe conditions of loading.

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## APPLICATIONS

INDUSTRIAL... as production test equipment, where quality control is desired and where production stoppages must be eliminated or minimized.

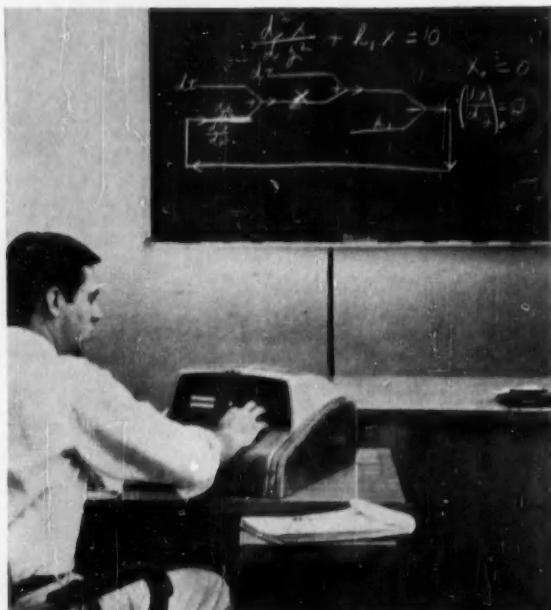
LABORATORY... as stable voltage references or bias supplies; as regulated filament supplies; as strain gauge or instrumentation supplies, etc.

ORIGINAL EQUIPMENT... as precision regulated and maintenance-free power source in automation, computer, communication and instrumentation equipment.



## Five Digital Advances from the West

It may be the climate, or it may be their nearness to the Creative Vortex of the Communicative Arts (Hollywood). But for sheer fecundity in new ideas and products the California Digital-Data Developers have few peers. Witness these five new offerings which first saw light this past November.

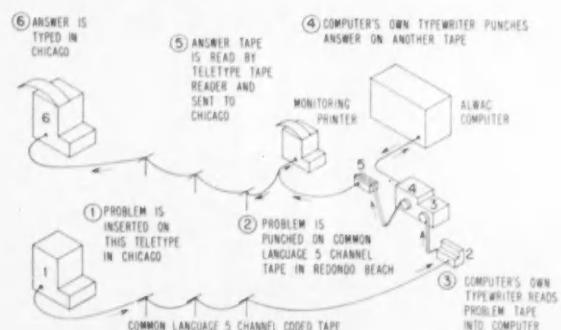


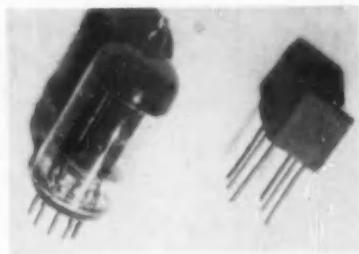
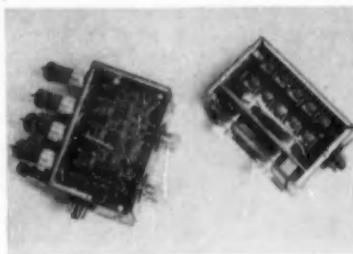
### 2. A LONG-DISTANCE COMPUTING SERVICE

The telegraph poles in the little sketch at the right—stretching 2,000 miles from Chicago's Navy Pier to Logistic Research's neat plant in Redondo Beach, Calif.—carried strange signals on Nov. 15. The pulses originated from complex rows of figures punched into a Teletype machine in the company's booth at the Automation Show (see page 20 for show details). They sped cross-country and fed into an Alvac computer at the plant. Seconds later a new group of figures—the computed answer—were neatly typed in the Chicago booth. Spectators at the show tried mortgage data, pet problems, amoeba-in-bucket gambits. The answers came back almost as the last number was entered. The desk at the right holds the plant's transmission and receiving equipment—a Western Union teleprinter machine using a 5-channel common language tape and a Flexowriter. In the background is the Alvac computer which converts the Teleprinter's 5-hole tape to 6-hole code, works the problem, then sends it to the Flexowriter again in 5-hole form. The resulting tape is read by a Western Union transmitter in California, then printed in Chicago. The company believes small laboratories and business will find this service will bring digital problem-solving well within their budget.

### 1. A PORTABLE DIGITAL DIFFERENTIAL ANALYZER

The neat little typewriter-sized box on the engineer's desk has a rather lofty price for the space it occupies (its maker, Litton Industries, suggests the \$10,000 range). But the price seems small when you consider the jobs it can do. Take the problem on the blackboard for example. Just a few flicks of the finger and the answer will come up on the little picture tube in the corner of the panel. No, it's not a closed loop to Norbert Wiener—this new device is a digital differential analyzer that packs twenty integrators, each accurate to one part in 250,000. It can handle any mathematical problem that can be put in differential form—does it by an iterative process that is completed 60 times per sec. The integrations, of course, must be preprogrammed. The tiny machine operates on 110 v and requires only 300 watts. It has plug-in components and a small magnetic memory. It can generate arbitrary functions and is easily coded to produce limiting or decision functions. As a matter of fact, its makers claim that it will tackle most problems normally relegated to the electronic analog DA—and goes the latter one better by handling equations that can have variable  $dx$  and/or  $dy$  inputs to each integrator.





### 3. A SOLID-STATE REDESIGN FOR A COUNTER

The handsome dual pre-set electronic counter, above left, on the surface looks like a more compact and functional design of the company's well-known line. But get inside the case and you'll find a small new decimal counting module replacing the standard vacuum tube version—see the substitute in the center picture. The picture on the right reveals how it's done. The Berkeley Div. of Beckman Instruments has gone over to Carl

Isborn's "Ferristor"—the new solid-state vacuum tube substitute discovered by this engineer for Berkeley early this year. The "Ferristor", actually a caramel-sized magnetic amplifier, handles all former tube functions: input amplifier, memory, gate, and relay controller. Besides savings in space and power, the circuits should bring much more reliability to industrial counters. With the exception of speed, most of the other characteristics of the new magnetic EPUT counter equal, if not exceed, the old vacuum tube model.

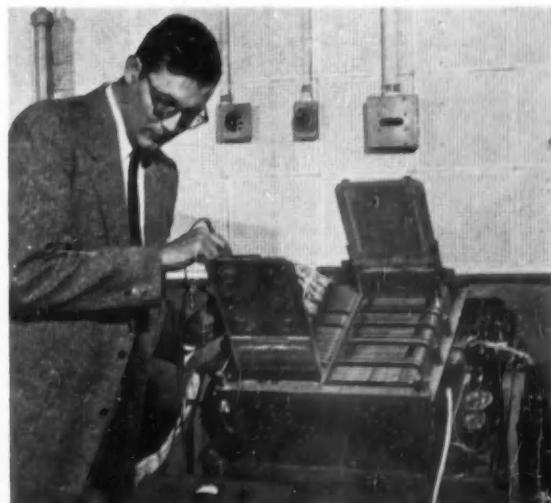


### 4. A COMPACT GENERAL-PURPOSE DIGITAL COMPUTER

The deceptively simple freezer-sized cabinet flanking the girl is actually the whole part-and-parcel of a new Librascope general purpose digital computer. Pull off the steel cover, however, and you'll find a beautifully compact three-section system on wheels: sliding drawer logic boards; a plug-in card section containing 100 vacuum tubes and 1,300 diodes; a magnetic drum memory. Also "under the hood": complete air conditioning and a self-contained power supply. The computing capabilities match the neatly designed innards. The machine will handle a 30-bit word length, plus sign and buffer. It has a 4,098 word capacity and a 3,600 rpm access speed. Its average access time is 8.5/1,000 sec.

### 5. AN AIRBORNE DIGITAL COMPUTER

The benchbound collection of wafers that the young man is investigating has just come back to earth after a highly successful flight test for function by its developer, North American Aviation's Missile and Control Equipment (MACE) Operations for the U. S. Air Force. Get closer to the thing, circle it, and you'll find it is a digital computer, completely transistorized to occupy only 3 cu ft and weigh only 125 lb. Further, to accomplish its function of processing in-flight data, it uses less than 100 watts power. A similar vacuum-tube computer with one-half the capacity would consume 3,000 watts. Etched circuits on copper clad plastic are also weight and size savers. Some 1,000 transistors are held on 51 of these standardized panels, which pull out like file cards for testing and replacement. The computer is able to integrate 93 quantities simultaneously and can generate continuous solution of differential and trigonometric problems.



Here's The "Inside Story" of  
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**GAGE VALVE**  
**SUPERIORITY**

Steel Locknut



Identification Plate



Steel Wheel or Lever



Steel Stem Packing Nut



Stainless Steel Standard or Quick-Closing Stem



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High Temperature Resisting Stem Packing



Stainless Steel Stem Packing Retainer



Forged Steel Body



Stainless Steel Ball



Stainless Steel Ball Retainer



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- CYCLING JET PUMPS
- INJECTORS

**PENBERTHY**

**WHAT'S NEW**



**ALL THIS, AND AN AIRFIELD, TOO.** Connected to Massachusetts' Grenier airfield by a short stroll is this new, half-million-dollar plant of Marion Electrical Instrument Co. The single-story, 40,000-sq-ft facility produces more than 80 per cent of all Marion components. The company's field-based plane provides quick access to all customers.

**All Around the Business Loop**

► Two manufacturers of control instruments have wound up their fiscal years in style. Figures are somewhat misleading in the case of **The Perkin-Elmer Corp.**, because slight declines in net sales and net income (down \$67,422 and \$55,055 respectively) far from tell the whole story. P-E's president and board chairman, Richard S. Perkin, reporting on the year that ended July 31, noted that shipments of commercial analytical instruments reached a record level of \$3,784,643 and that new orders for such instruments increased 16 per cent over fiscal 1954. Military sales (40 per cent of P-E's business) reacted according to expectations and it was this anticipated lag between successive defense production contracts that accounted for the dip in net sales. New orders in all categories rose to \$7,743,000, a 32 per cent increase over the previous year, and increased the backlog to \$6,818,000. These figures, of course, reflect operations prior to the October flood, which Perkin-Elmer weathered so meritoriously (see December issue, page 28).

► **Varian Associates**, in its report covering the year ending Sept. 30, noted that for the first time in its history sales of industrial and scientific instruments and electronic systems exceeded 8 per cent of total sales. In fact, products in this class produced nearly one fifth of the entire volume. The klystron vacuum tube, the company's best known product, accounted for 82 per cent. Dollar figures were: sales up \$1,259,000, backlog up \$2,435,000, and net earnings, at the end of the year, \$433,000. Included in the consolidated figures is \$19,000, the profits from the new subsidiary, **Varian Associates of Canada, Ltd.**, which recently finished its new home in

Georgetown, Ontario. Varian plans to spend close to \$500,000 in this fiscal year on new product research.

► Other companies have submitted bright reports for the first nine months of calendar 1955. Among them: **Thomas A. Edison, Inc.**, with consolidated profits after taxes of \$900,162, up 80 per cent or \$399,289; sales of \$26,038,159, up \$497,596, and net earnings of \$328,784, up \$287,514; and **General Controls Co.**, with sales of \$19,249,458, more than for all of 1954, and net earnings of \$1,156,664, up \$439,391. President W. A. Ray expects total gross sales for 1955 to hit \$27 million, which would be an all-time high for the Glendale, Calif., company.

► **Fairchild Camera & Instrument Corp.** has brought in one of the Navy's top nucleonics experts to head its new **Nuclear Instrumentation Dept.** Being considered for development and manufacture by Dr. Harold E. DeBolt's unit are radiation monitoring equipment, control rod drive mechanisms for atomic reactors, neutron detectors, and associated temperature, pressure, and flow controls. These packaged reactor controls will be designed primarily for commercial applications, but to some degree, too, for the military. One outlet in the latter category: the Aircraft Nuclear Propulsion Program of the Air Force's Air Development Command. DeBolt most recently was with the Nuclear Power Div. of the Navy's Bureau of Ships and the Naval Reactor Branch of the AEC's Reactor Development Div. ► In its **Arizona Research Laboratories** in Phoenix, **Motorola** is producing the new very-high-frequency diffused base transistors on a pilot-plant basis. This is the first announcement of any successful venture into commercial production of the new transistor since its development by Drs. William Shockley and George Dacey of the Bell

## WHAT'S NEW

**Telephone Laboratories**, and is one of a pair of announcements to be made by Motorola. The other: the company is getting set for semi-automatic manufacture of the transistor. The diffused base technique permits production of transistors for frequency ranges as high as 1 billion cycles per sec, at which range they are applicable to every kind of communication system. It will be two or three years, however, before this general application becomes practicable, Motorola's vice-president, Daniel E. Noble, believes.

► Two upstate New York cities figure in the formation by **IBM** of a new **Military Products Div.**, whose general manager is Charles F. McElwain. At Kingston, General Manager Gavin A. Cullen will direct IBM's part of Project Lincoln, a government effort involving production of ground-based computers for the continental air warning network. MIT is collaborating with IBM on this project. And at Vestal, near Binghamton, the second area of the new division is taking shape under Curt I. Johnson. Participating at Vestal are Johnson's **Airborne Computer Laboratory** and production facilities for advanced electronic bombing and navigational systems. McElwain, formerly director of defense engineering and manufacturing, will supervise operations from administrative offices in New York City. The new division now holds the same autonomy as IBM's **Electric Typewriter Div.**

IBM isn't telling what kind of machine it's developing and producing on a pilot basis at San Jose, Calif. It has revealed, however, that it has leased a 20,000-sq-ft building for the project and that work is already under way.

► Service facilities for handling electronic instruments are being expanded across the U.S. by **Allen B. Du Mont Laboratories, Inc.** One big reason for the move is that the company now is marketing a number of general-purpose electronic instruments and engineering a new line of cathode-ray oscilloscopes. Du Mont plans to put the **Technical Sales Dept.** under a dual administration, service to be headed by F. William Scharpwindel and parts sales by Rudolph H. Arp.

Du Mont's new West Coast headquarters plant, which recently went into operation in Los Angeles, gave the company six times as much space as its former facilities there. Included are 30,000 sq ft of working space, a railroad siding, and a parking area.

# EPSCO

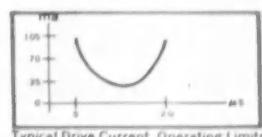
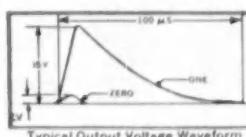
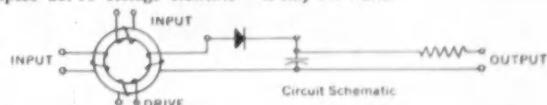
small size • low power • rugged • reliable

New Epsco Magnetic Storage Elements Type SR-11 are designed for airborne and missile applications. Due to their extremely low power requirement, they may be driven by either subminiature tubes or transistors.

Measuring only  $\frac{3}{4}'' \times \frac{3}{4}'' \times \frac{1}{16}''$ , these new subminiature units are entirely suitable for mounting on etched wiring boards. Epsco SR-11 storage elements

also offer the advantages of high ratio of storage elements to drive tubes. Wide operating limits and encapsulated packaging insure the ultimate in reliable performance.

SR-11 elements have an information rate design center of 10 kc, with a practical upper information rate of 15 kc. Peak power per shifted "one" at design center is only 0.5 watts.



For full information on Epsco Magnetic Storage Elements, write for Engineering Data Sheets.



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# Designing Automatic Controls



NORTH SENSITIVE RELAY Type Ir-226

Hermetically Sealed—Sensitive Type—Temperature Range -65° to +125° C—Zero Bounce or Chatter at 50 Gs Shock and 500 Cycle Vibration Tests—SPDT at 20 mw, DPDT at 40 mw. coil input—100,000 Operations at Rated Load of 2.0 amps at 30v DC resistive.

. for application fitness

. . for high reliability

. . . for long life

....Specify

# NORTH RELAYS

Catalog upon Request

INDUSTRIAL DIVISION



NORTH ELECTRIC COMPANY

526 South Market Street, Galion, Ohio

## WHAT'S NEW

► The complete engineering and design file of Stockwell Transformer Corp's liquid-filled and air-cooled transformers has been purchased by Precision Transformer Corp. The range of these transformers is to 3,000 kva.

► Under a new agreement, Ohmite Mfg. Co. will produce the Amrecon relays formerly made by American Relay & Controls, Inc., at one time a subsidiary of Ohmite. They'll take on the new name of Ohmite Amrecon relays and will continue to emanate from Ohmite's plant in Skokie, Ill.

► When an exchange of shares between Link-Belt Co. and Syntron Co. has been consummated, Syntron will become a Link-Belt subsidiary.

► On the way up: a new manufacturing plant—157,000 sq ft—in Syosset, Long Island, for Kollsman Instrument Corp., to be completed next fall; and an addition—44,000 sq ft—to Beckman's Berkeley Div. in Richmond, Calif., to be completed by the middle of this month.

► Opened: a three-story plant (33,000 sq ft) in Bristol, Pa., by Bristol Engineering Co.; a subsidiary plant (12,000 sq ft) in Ames, Ia., by Bourns Laboratories; a new facility (Timely Instruments & Controls, Corp.) in Gardena, Calif.; an eastern regional sales office in New York City by Texas Instruments, Inc.; and a west Coast office in San Francisco by the Research & Control Instruments Div. of North American Philips Co., Inc.

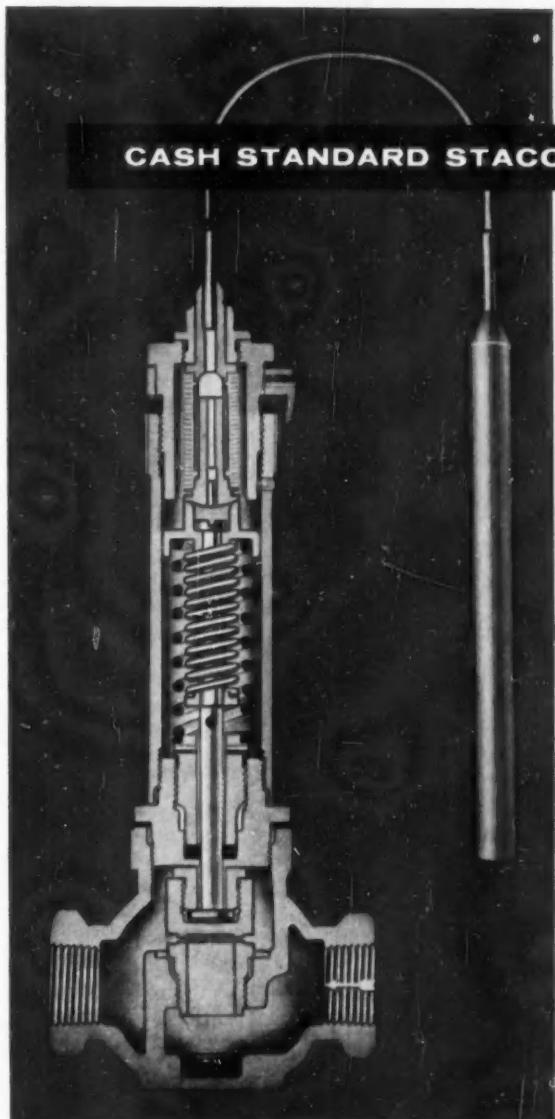
► Recent acquisitions: Phebco, Inc. (electronic equipment for industrial use; radar and guided missiles) by Hoover Co., which with this step extends operations beyond the field of household cleaning appliances; and Farris Stacon Corp. (temperature control valves) by A. W. Cash Co.

► And a merger: Electric Controller & Mfg. Co. and Square D Co.



TECHNICIANS ABROAD Marty Laden-Brown Instruments' energetic education director—points out features in the ElectroniK to students in Minneapolis-Honeywell's new training school at Perivale, England.

# Cash Standard Expands by the addition of Stacon Temperature Regulators

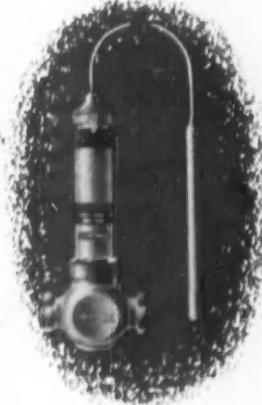


## CASH STANDARD STACON TEMPERATURE REGULATORS

This line of temperature regulators (formerly manufactured by Farris Stacon Corp.) rounds out complete Cash Standard line of valves to solve any problem of temperature regulation or pressure control.

- Provide accurate temperature control for use with steam, liquids and gases.
- Self-operating and self-contained pilot-operating.
- Direct and reverse acting.
- Liquid filled thermal system for high operating power and uniform throttling action.
- Extremely compact construction with rugged field-replaceable thermostatic system.
- Overload protection to prevent overstressing of thermostatic system at over-range temperature.

Recommended for hot water heaters, tanks, kettles, plating tanks, bottle and can washers, degreasers, ovens, fuel oil heaters, brine circulating, process cooling, jacket cooling for compressors, diesel and gas engines, and many other uses.



### What Is Your Temperature Regulation Problem?

Cash Standard has  
the Answer!

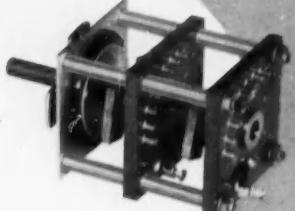
Contact your Cash Standard control specialist  
or write Dept. F.

**CASH**  **STANDARD**

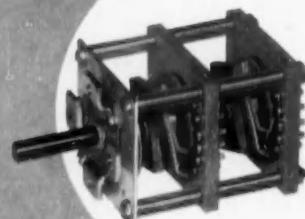
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### WHAT'S NEW



L. L. Wheeler



Raymond Meyer



W. C. Norris



M. L. Rice



Joseph Tampico



Arnold Raines

#### Important Moves by Key People

► **Dr. L. L. Wheeler** is the new chief engineer of Sperry Gyroscope Co. A specialist in weapon system engineering, he directed the project that resulted in today's K-bombing navigational system. He has been assistant chief engineer since 1951. Leaving the post of chief engineer for that of vice-president for research and development is **Dr. W. L. Barrow**, who was an associate professor at MIT before joining Sperry in 1943. Barrow, who became vice-president and chief engineer in 1952, directed a number of wartime projects in fire control and armament engineering. He has been an advisor to the armed forces for the past 14 years. **George A. Richroath**, who has been named vice-president of manufacturing, leaves his works manager post to **Samuel Agabian**. Mr. Richroath joined the Sperry Gyroscope Co. in 1941. Agabian in 1940.

► Acting on the advice of economists, who see big gains for its production facilities, ElectroData Corp. has established a new post, that of supervisor of manufacturing, and filled it with **Raymond Meyer**, formerly administrative assistant to the vice-president. Meyer moves into the job as ElectroData prepares for a major ex-

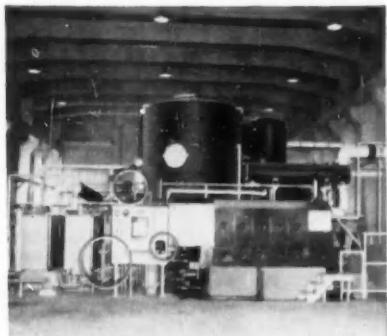
pansion in output: three complete Datatron computer systems a month, starting this fall.

► When **William C. Norris**, vice-president of Remington Rand, became general manager of the new Univac Div., these facilities were consolidated under his supervision: the Eckert-Mauchly Div. at Philadelphia; the Engineering Research Associates Div. at St. Paul, the Tabulating Div., and the Laboratory for Advanced Research at Norwalk, Conn. All electronic computer and tabulating machine operations have been funneled into the new division, for which a 200,000 sq ft electronic laboratory will be built in St. Paul.

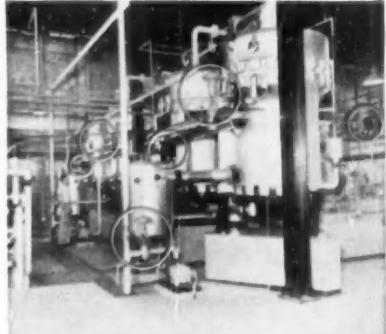
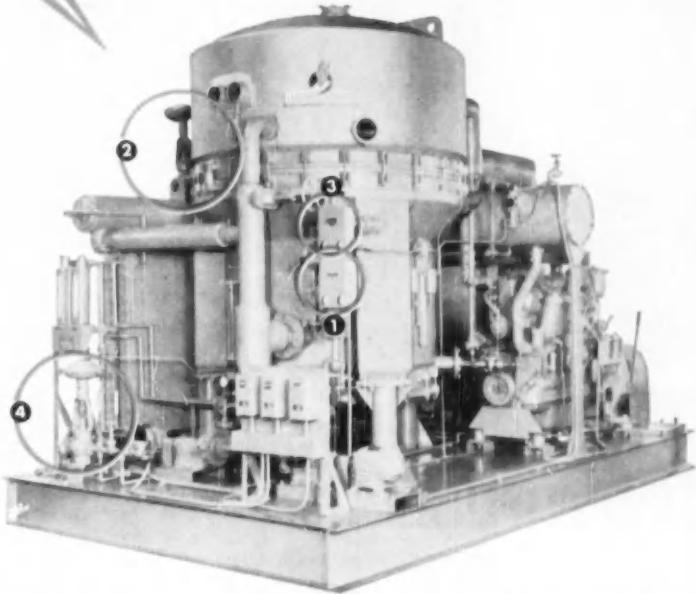
► Atlantic Research Corp. has brought its Applied Mathematics and Interior Ballistics Project Group "up from the ranks" and made it a division. Director is **Millard Lee Rice**, who joined the staff in 1950 and has been director of the unit since its formation as a group in 1954. At the same time a new Technical Information and Library Planning Group has been organized under **Saul Herner**, technical information specialist. The group will consult and do research in technical information and communication.

► Associated Missile Products Corp., the eight-months-old subsidiary of American Machine & Foundry Co., has named **Dr. Joseph Tampico** di-

# This Cleaver-Brooks Unit Converts – SEA WATER INTO FRESH WATER



At the time of its installation at the Kindley Air Force Base in Bermuda, this Cleaver-Brooks unit and three others like it constituted the world's largest vapor compression sea water distillation plant. Total daily capacity of the installation is more than 200,000 gallons. BS&B Automatic Controls are standard equipment on all units.



Largest compression still installation in the United States for producing distilled water is this West Coast metropolitan area plant which commercially produces more than 100,000 gallons of distilled water daily. All units are Cleaver-Brooks. Note BS&B Automatic Controls visible in the picture.



This Cleaver-Brooks Diesel Drive Compression Still produces more than 14,000 gallons of U.S.P. chemically pure and pyrogen free water per day from brackish or sea water. It is automatically controlled by (1) a BS&B Type 1400LP Low Pressure Pilot which operates (2) a BS&B Type 86R Valve to control the evaporator pressure, and by (3) a BS&B Type 887 Liquid Level Controller which operates (4) another BS&B Type 86R Valve to control the evaporator liquid level.

## ... With The Help Of BS&B AUTOMATIC CONTROLS!

When a manufacturer of heavy industrial heating and process equipment selects the automatic controls to be used as "original equipment" on his units, he must be *certain* that they will operate just as efficiently and dependably as the unit they are to serve.

That is why Cleaver-Brooks Company, of Milwaukee, and many other manufacturers have standardized on BS&B. They know that BS&B Automatic Controls can *always* be counted on for precise accuracy, superior quality, long life and outstanding performance!

Why not make BS&B Automatic Controls your *first* choice too—both for "original equipment" and for replacements? Your BS&B Representative will be glad to give you detailed information. Or you may write to...

**BLACK, SIVALLS & BRYSON, INC.**

Controls Division, Dept. 4-ES1

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# High gain

.. small package!



## PRD TRANSISTOR-MAGNETIC SERVO AMPLIFIER

- weighs only 21 ounces
- measures 3 1/2 x 2 1/2 x 2 1/2

The Type R40G7W6 is a small transistor-magnetic amplifier which is specifically designed to drive parallel connected Belden MK7 and MK14 400 cps servo motors from potentiometer, synchro or resolver data. The unit has a built-in silicon transistor preamplifier and requires no stabilizer, demodulator or d.c. power supply. Truly remarkable performance is achieved with this unit as can be seen from the complete specifications.

### Specifications

Maximum output: 7 watts, 57 v a.c., 400 cps  
 Voltage gain: with MK7 motor 2000 with MK14 motor 2400  
 Bandwidth: 0 - 70 cps  
 Zero drift: less than 3 mv ref. input  
 Saturation Signal: 50 mv  
 Input impedance: 15,000 ohms  
 Amb. temperature: -55° to +85°C  
 Stabilization: Internally provided  
 Power supply: 115 v ± 10%, 400 cps  
 Hermetically sealed.  
 Meets MIL-E-5272, Procedure 1, Vibration Specifications.

Write for complete folder on PRD Magnetic Amplifiers

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## WHAT'S NEW

rector of engineering and **Earl R. Skaggs** assistant general manager, a new position. Tampico, a vice-president, has been director of research, and Skaggs, also a V-P, formerly was director of product engineering.

► The two men who have taken charge of Norden-Ketay Corp.'s new Western Div. at Gardena and Hawthorne, Calif., were both formerly with the Arga Div. of Beckman Instruments, Inc. They are **Arnold Raines**, general manager, and **Herbert Galman**, manager of the Engineering Dept. Plants at the two cities will carry out research, engineering, development, and sales and service on a completely self-sufficient basis. N-K's manufacturing operation in California has been integrated into the new division.

► **Perry C. Smith**, the new manager of the Equipment Dept. of Clevite Corp.'s Brush Electronics Div., was general manager of the Electronics Instruments Div. of the Burroughs Corp. before joining Brush early in 1955. Prior to that he was manager of scientific instruments engineering for RCA. Clevite Research Center, which does research and development work for all Clevite units, has named **J. Kneeland Nunan** to the new position of vice-president and general manager. Nunan, who most recently was president of Consolidated Vacuum Corp.,

has built up an impressive background as a result of experience with the following organizations: Consolidated Engineering Corp., Hughes Aircraft, Trans-World Airlines, Anasco Div. of General Aniline & Film Corp.; Aerocet Div. of General Tire & Rubber Co., Navy Underwater Sound Laboratory, and the scientific staff of the Div. of War Research at Columbia University.

► **Seymour Blechman** brings 15 years' experience in flow measurement and control to his new post of executive vice-president of Brooks Rotameter Co., where he will coordinate and guide product improvement and expansion. Most recently he was with Fischer & Porter Co. as vice-president and sales manager.

► When **Harold E. Carlson** moved from manager of the Eastern Div. of Servomechanisms, Inc., to program controller, **Gerard Q. Decker** took over at the Westbury, N. Y., division headquarters. As program controller, Carlson joins the executive office staff. Decker was formerly with Rheem Mfg. Co.'s Government Products Div.

► ESC Corp.'s high power pulse forming networks are unique in the industry, now that a brain has been added. To be specific, **Bernard Brain**, who as a department head, will have technical responsibility for design and de-



P. C. Smith



Seymour Blechman



G. Q. Decker



Bernard Brain



W. H. Kushnick



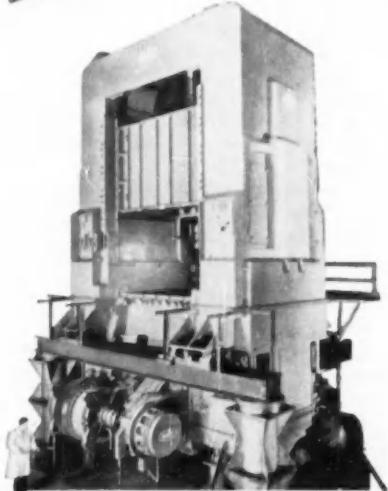
Oliver Mueller



# DYNAMATIC

## EDDY-CURRENT EQUIPMENT

is Solving Speed Control Problems in Every Major Industry

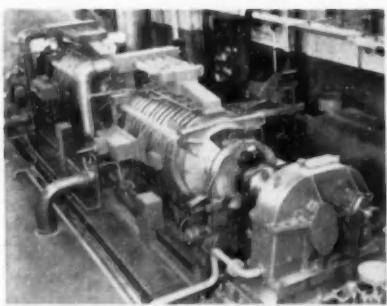


800 ton double-action under-drive metal forming press, driven by Dynamatic model 37-32 combination eddy-current coupling and brake.

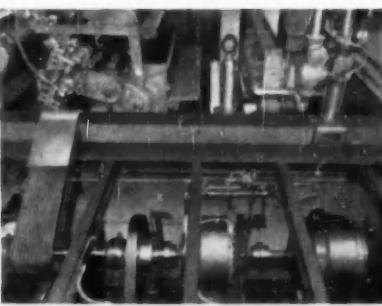
In practically all testing, processing, and conveying equipment common to industry, Dynamatic eddy-current rotating equipment is solving a wide range of adjustable speed drive problems, particularly where an AC power source is a requirement.

Advantages include rapid response, stepless adjustable speed control, wide speed range, quiet operation, low power loss, low maintenance cost, adjustable speed from an AC power source.

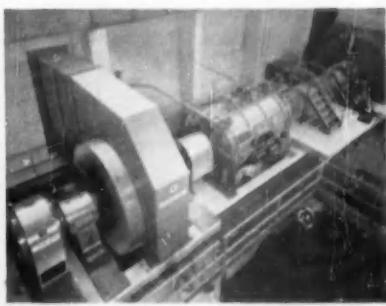
Send for Bulletin GB2, which describes and illustrates the basic Dynamatic eddy-current units, including couplings, brakes, dynamometers, press drives, and Ajusto-Spede® drives.



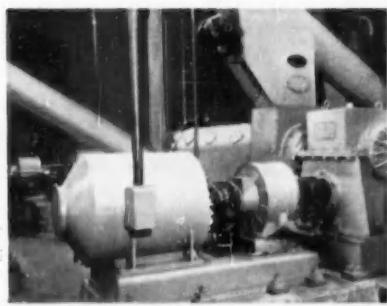
Tandem Dynamatic dynamometers, rated 20000 H.P., 600 to 5800 RPM. A cradled gear box permits turbine testing to 15000 RPM.



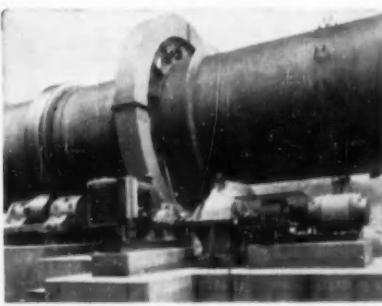
Model WC-1308 Dynamatic adjustable speed eddy-current coupling with eddy-current brake, used as printing press drive. Rated 20 H.P. at 1700 RPM.



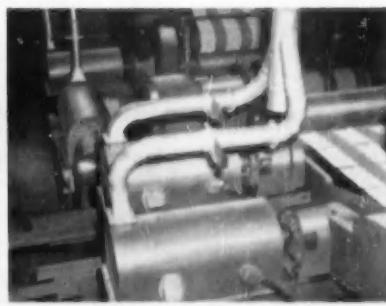
Dynamatic adjustable speed eddy-current aircraft wind tunnel drive, 18000 H.P. at 480 RPM.



Paper pulp washer driven by Dynamatic model WC-160 adjustable speed eddy-current coupling, rated 125 H.P. at 1100 RPM.



Dynamatic model WC-160 adjustable speed eddy-current coupling, rated 100 H.P. at 1100 RPM, used as cement kiln drive.



Roofing material machine driven by 23 Dynamatic Ajusto-Spede® drives. All drives and controls completely enclosed and forced ventilated.

# EATON

— DYNAMATIC DIVISION —  
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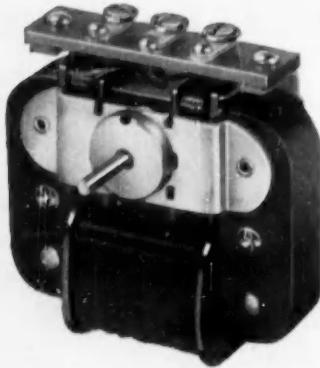
# Small Motors

**new free catalog helps select exact motor needed**

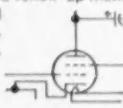
Get this helpful new catalog of Barber-Colman a-c shaded pole motors. Designed for applications requiring long life, rugged construction, these quality motors with high starting torque, low-inertia rotors provide quick, positive starting under adverse conditions. Various models of the four types shown below.



## REVERSIBLE MOTORS



Adaptable to a variety of control circuits to meet many different requirements demanding a compact and powerful fast-reversing motor. Widely used for servo-mechanisms, remote switching and positioning devices, voltage regulators, pen drives. Available with gear trains, open or enclosed, in wide range of ratios. Low-inertia rotors permitting rapid reversing and follow-up make these motors ideal for many electronic control circuits.



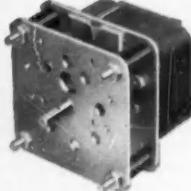
### UNIDIRECTIONAL

For driving pumps, projectors, blowers and fans for refrigerators, gear trains for vending and office machines, etc.



### SYNCHRONOUS

For chart drives, timers, microfilm cameras, oscillographs, and similar applications.



### GEARED

For vending and office machines, rotisseries, TV tuners, program switches, etc. Model shown for overhanging loads.

**the complete line of Barber-Colman motors** includes unidirectional, synchronous, and reversible motors — up to 1/20 hp. With and without reduction gearing — open or enclosed types. Expert engineering service available to help you get the exact motor for your application. Write today for your free copy of new Catalog F-4271-6.

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Small Motors • Automatic Controls • Industrial Instruments • Aircraft Controls • Air Distribution Products  
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## WHAT'S NEW

velopment of the networks. Brain was instrumental in development of PTM communications systems by Federal Telecommunications Laboratories, with which he associated for 10 years.

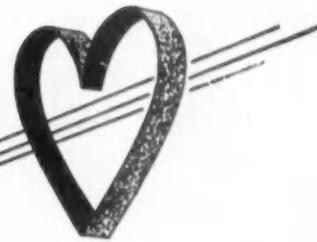
► **William H. Kushnick**, executive director of ISA, has been appointed chairman of a special committee that will review the personnel recommendations made by the Hoover Commission on the business organization of the Dept. of Defense. Kushnick's appointment was made by that department.

► **Oliver Mueller**, who has been named chief engineer of the Aircraft Controls Div. of Gorn Electric Co., has been chief engineer of Fischer & Porter Co. and chief tool engineer of the Ordnance Div. of Bell Aircraft Co. ► Concurrent with the retirement of **Carl H. Bissell**, vice-president for engineering, these executive appointments have been made by Crouse-Hinds Co.: **Albert H. Clarke**, commercial vice-president, to succeed Bissell; **Jay R. Petree**, assistant chief engineer, to chief engineer, and **John R. Haney**, to succeed Clarke as manager of the Illumination Dept. Bissell, a pioneer in electricity, conceived the first automatic traffic signal controller and fostered development of Crouse-Hinds' explosion-proof electrical equipment for hazardous areas. He joined the company in 1901.

► Two research scientists, whose fields are principally physics, have been named associate directors of the Westinghouse Research Laboratories. They are: **Dr. Daniel Alpert**, whose work in ultra-high vacuum research culminated this year in coveted recognition by the American Association for the Advancement of Science, which stamped one of his papers the most noteworthy one presented at its session in Berkeley, Calif.; and **Dr. Aaron Wexler**, whose low temperature laboratory, established by him at Westinghouse in 1947, has received international acclaim for studies of electrical and magnetic properties at temperatures as low as a fraction of a degree of absolute zero. Alpert joined Westinghouse in 1941, Wexler in 1947.

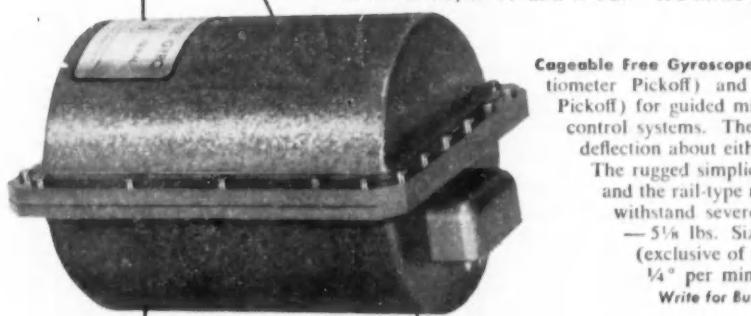
► **Dr. Leland G. Cole**, who last year directed the dynamics laboratory of Robertshaw-Fulton Controls Co., has been named to the research staff of Consolidated Engineering Corp. At the same time **Kenneth Hines**, a research chemist formerly with Shell Oil Co.'s Houston refinery, joins the company as a project engineer in the Systems Div.

THE HEART OF THE HOMING SYSTEM



## *Doelcam* Master-precision Gyroscopes

DOELCAM Master-precision Gyroscopes and Gyro Stable Platforms are standard equipment in many of today's missile and aircraft stabilization and guidance systems. Shown here are three standard models. Specialized versions of these models or completely new designs can be produced in quantity to suit your requirements *exactly*. Avail yourself of the same engineering know-how that has successfully designed gyros for the LARK, METEOR, TALOS, RASCAL, BOMARC and LACROSSE Missiles and the same production team that has made DOELCAM the largest single producer of gyros for the bombing and navigational computer used in the B-36, B-47 and B-52. *We invite your inquiry.*



**Cageable Free Gyroscopes, Type CFG-P** (Potentiometer Pickoff) and **Type CFG-S** (Synchro Pickoff) for guided missile instrumentation and control systems. These gyros measure angular deflection about either one or both gimbal axes.

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*Write for Bulletin CFG-34.*



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**Rate Measuring Gyroscopes, Type JR** for tactical weapon systems requiring less than one minute warmup. Incorporate damping compensator for constant damping ratio without heater. Linear output signal proportional to input rate within 0.25%. Withstand 50G shock, 15G vibration up to 2000 cps. Angular Momentum —  $10^6$  gm.-cm.<sup>2</sup>/sec. Size 3¾" long x 2.0" diameter. *Write for Bulletin JG-34.*

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## WHAT'S NEW



Flanking Dr. Joseph W. Barker, of ASME, are engineer-tourists Vladimir P. Loukine (left) and Georgi P. Kazanski, both of Moscow.

## Soviet Control Engineers Unmoved by U.S. "Automation"

Whoever in our State Department labeled the two visiting Soviet control engineers "automation experts" made a sad mistake: as a result the two specialists were taken on a misguided two week whirl of standard big-plant facilities, with the accent on transfer and production rather than measurement and feedback.

At the press conference at tour's end, the Russian's comments could almost be predicted. When asked what they thought of the "highly automated" plants they saw, they replied, "We saw nothing new." And asked to name the most "interesting thing," the answer was, "The most interesting thing is that we did not see what we wanted to see."

The visiting engineers—V. P. Loukine of the Soviet Machine Construction Ministry, and G. P. Kazanski of the Radio Technics Ministry—were much more disappointed than ironic. Actually, they had nothing but praise for the ASME, who acted as their host on the tour. And for their reception across the land. But it was obvious that they knew that advances in the art of control did exist here and that their itinerary, arranged along "automation" lines, frustrated their chances to see these things.

#### Parallel Developments in USSR

At the press conference CONTROL ENGINEERING's representative attempted some questions about various aspects of control in USSR. Here are some of the comments he received:

► **Digital Computers** — apparently USSR has developed large numbers of large-scale digital computers. These are mainly being used in tackling scientific research problems and in sta-

tical data processing. One recently developed Soviet computer is capable of solving differential equations of the sixth order.

► **Machine Control**—they saw no closed-loop or measurement techniques on U. S. machinery in their tour that has not its parallel in USSR. Apparently the Machine Construction Ministry is deep into continuous gagging problems.

► **Solid-State Devices**—USSR was held to be at about the same level in development in using transistors and other solid state devices as the U. S. However, Mr. Kazanski indicated that Russian engineers were stressing this approach more in the design of industrial measuring equipment than in commercial communications.

► **Refinery Control**—one plant in the Russians' tour was the Standard Oil refinery in Cleveland. The control panels there did not impress them. They claimed that similar installations have been in USSR for the past 15 to 20 years.

► **Electronics in Control**—the visiting engineers estimated that about 20 per cent of all measuring apparatus in USSR control systems employed electronic techniques. They claimed that Soviet production of electronic equipment has gone up five-fold in the past five years.

It was apparent that the visitors were highly skilled engineers and very well steeped in control theory and application. Our editor, near the end of the conference, suggested that they return this spring for the IRE show, and next fall for the ISA conference. And for an industrial tour guided by trained control engineer.

*the "inside" story.*

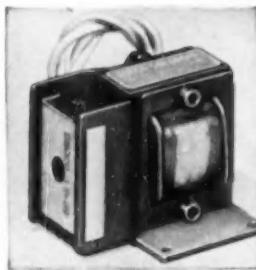
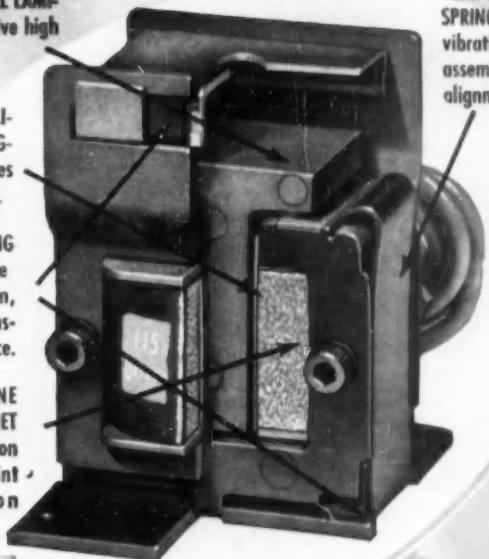
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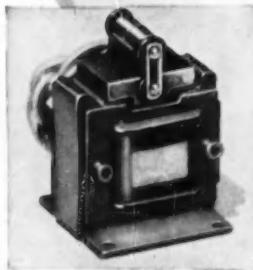
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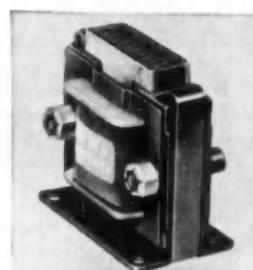
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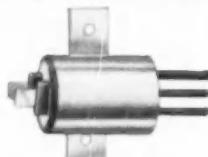


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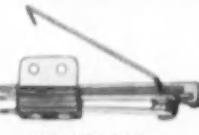
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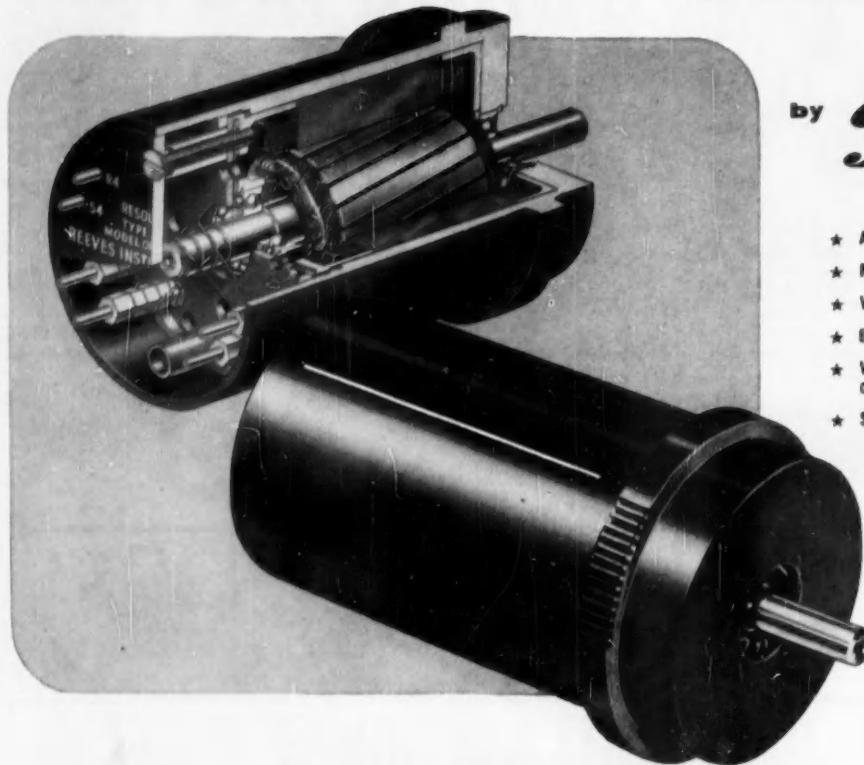
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Write for the Reeves Resolver Handbook.

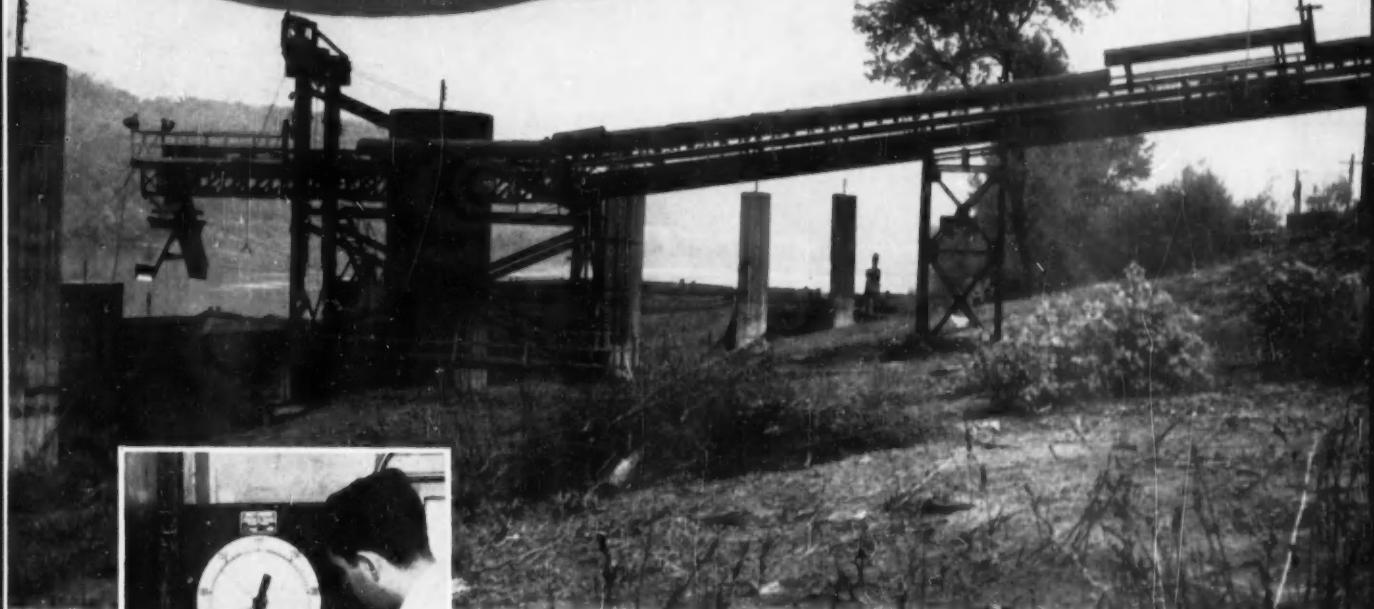


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## Baldwin SR-4® Load Cell simplifies materials weighing at The Valley Camp Coal Company

Continuous electrical weighing of coal moving on a conveyor belt to river barges has simplified measurements of coal shipments and mine production at The Valley Camp Coal Company, Moundsville, W. Va. Furthermore, this new system gives greater assurance of bills of lading than those determined by water displacement of barges.

Heart of this weighing system, designed by Trans-Weigh Co., Wayne, Pa., is a 300-lb. Baldwin SR-4 Load Cell. Installed under the conveyor belt, this cell takes tensional loads and transmits weight signals electrically to a recording instrument in a distant mine office. Here the recorder shows instantaneous rates of flow of coal on the belt in tons per hour, a continuous circular chart record of flow rates and the total tonnage of coal carried on the belt to barges. Another totalizing counter at an

operator's position on the dock adds to the convenience of the system. Accuracy of this system has proved to be within 1%.

Valley Camp also uses their weighing system to check estimated tonnages coming out of the mine in mine cars and to make more accurate daily reports of coal handled.

You too will benefit by using Baldwin *Packaged Precision Measurement*. Highly accurate SR-4 Devices are ruggedly built to take severe impacts and overloads. There are no moving parts to wear out. They're sealed against dust, dirt and moisture. Send today for our new booklets detailing uses of SR-4 Device systems to measure electronically either load, torque or fluid pressure.



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Please send me the following new literature:

- Bulletin 4300 (Introduction to SR-4 Devices)
- Bulletin 4301 (SR-4 Load Cells & Load Beams)
- Bulletin 4304 (SR-4 Crane Scales)
- Bulletin 4302 (SR-4 Weighing of Tanks, Bins, Hoppers)

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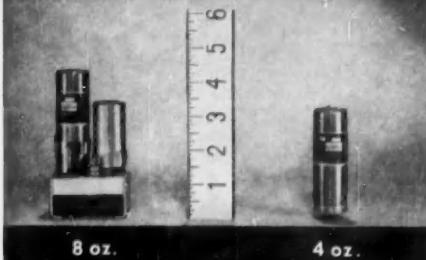
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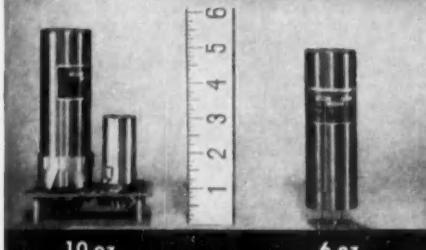


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**PRECISION FORK UNIT**  
200 to 4000 Cycles

Type 2003  
± .02% at -65° to 85°C  
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± .002% at 15° to 35°C  
Type W 2003  
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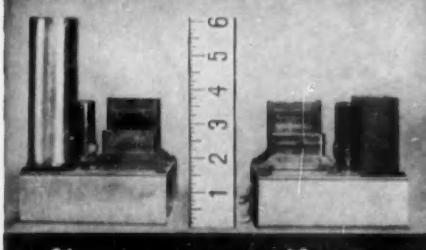
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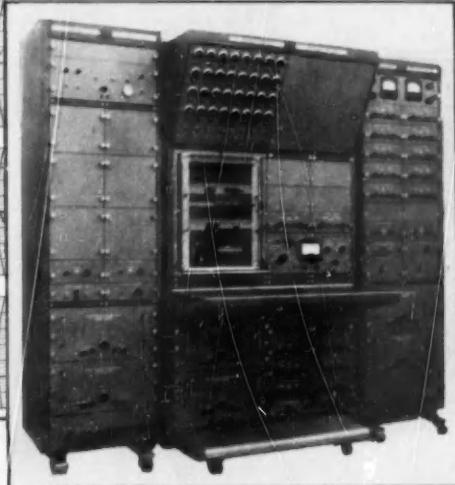
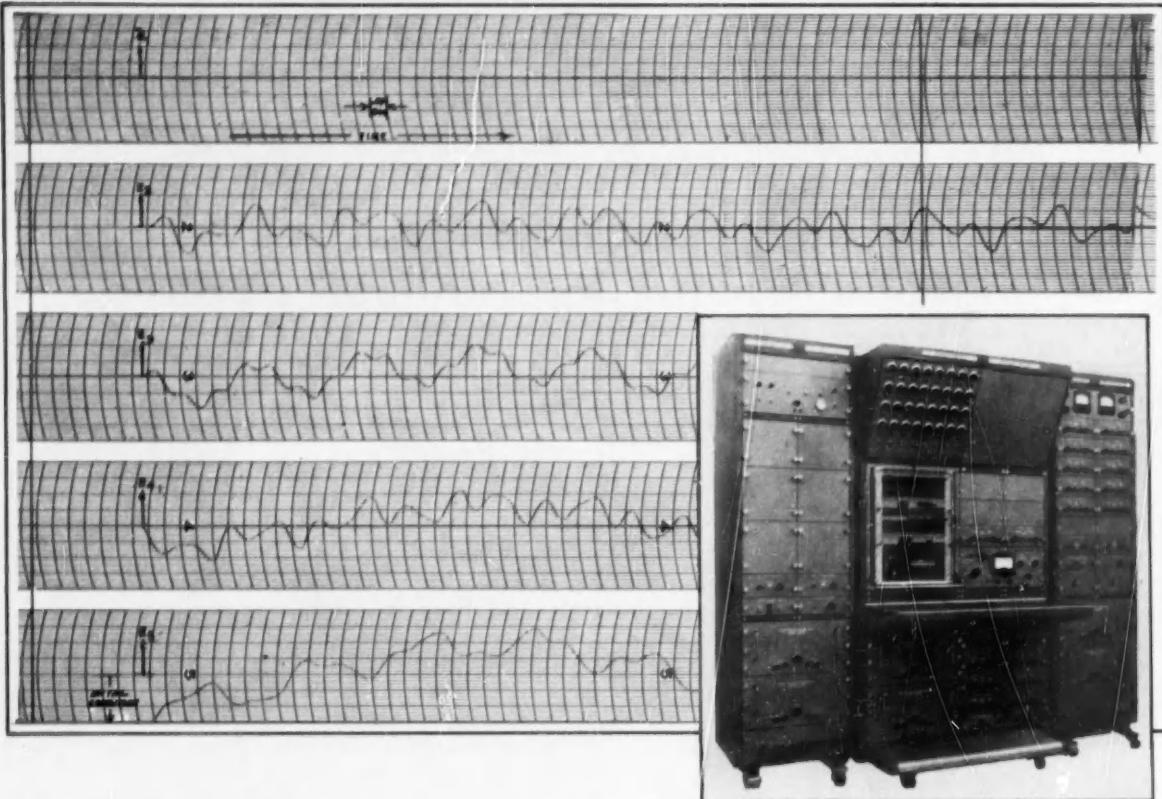


Now, a controlled-volume proportioning pump for laboratory application, pilot plants, and industrial production, where requirements are for pumping of precise volumes at micro-flow rates without risk of leakage or contamination of fluid being pumped. The "Microflo" Pulsafeeder combines the best features of both piston and diaphragm pumps by using a piston for constant volume measuring purposes and a diaphragm to seal the product pumped against leakage or contamination. All liquid handling parts have been selected for their resistance to corrosion. Maximum pumping capacity is 2150 ML. per hour, maximum discharge pressure 1000 psig. Pumping rate of the "Microflo" Pulsafeeder can be manually adjusted while the pump is idle or operating, or if desired, complete operation can be governed by automatic controls.

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An engineer was anxious to determine the vibration and stress of a beam, one end of which was to be solidly built into the support while the opposite end was to be unrestrained.

This engineer accomplished this on an EAI Analog Computer while the beam was still in blueprint stage. For on this computer, he was able to produce various modes of vibration by applying appropriate initial conditions at each of the nodes. The response of the nodes when an initial displacement of the tip station is suddenly released can be observed in the above illustration.

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## INDUSTRY'S PULSE

# Control Stacks Up Mighty High Ahead

Launching makers and users into a promising new year are two rather incredible—but well validated—figures on the immediate and future potential for automatic control, just released by McGraw-Hill's Department of Economics:

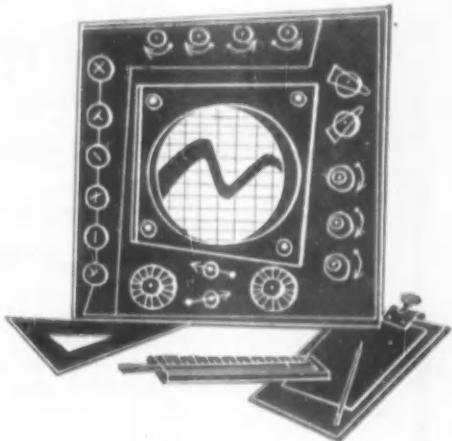
- An overall plan by manufacturing industry to spend 30% more for new plant and equipment in 1956 than it did in 1955—that's close to an increase of \$3 billion.
- A projected five-year advance by all industry from a current \$385 billion gross national product to \$440 billion in 1960—a growth in which the control field will lead all others by 50%.

The McGraw-Hill annual estimates on capital spending plans, based on a questionnaire mailed to a cross-section of business and industry people early each fall, long have been considered one of the most accurate indicators of the business outlook. But results of the last survey astonished even the economists who made it: huge upsurges on top of a record \$29.4 billion spending in '55—almost as great as industry's expansion in 1951, when the Korean War began.

Specific plans by certain manufacturing groups are eye-poppers. Iron and steel firms top the list with a prospective increase in spending of 72%—from \$865 million in '55 to \$1,488 million in the coming year. Auto makers also plan a giant buying spree. Their expenditures last year—\$1.1 billion—are dwarfed by an expected \$1.9 billion in '56. The non-ferrous metal makers will run third with a 54% boost in new plant and equipment (\$173 million more than in the past year).

Other traditionally large users of control also will have many more dollars to spend. Samples: chemical—up 34% to \$1,383 million; paper—up 30% to \$640 million; transport equipment (largely aircraft)—up 14% to \$319 million; oil refining—up 14% to \$825 million. Gains in others will be more modest: textiles—10%; machinery—7%; ceramics—7%; food—5%.

A paradox is revealed in the plans of certain other industries. In this group were the instrument and control makers—and they report a planned increase in new plant in 1956 of only 2%. Yet we are told that control production was stretched



**It even amazed  
the case-hardened  
economists**

**Will control be  
all sold out?**

# FORD INSTRUMENT

solved one design problem by

## CASCADING RESOLVERS

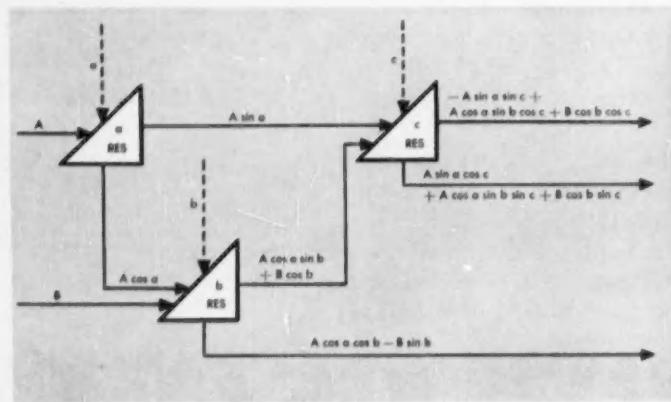
WITHOUT

### ISOLATION AMPLIFIERS

To get around a problem that arises in almost every resolver application Ford engineers recently designed a computer which, among other things, employed a chain of cascaded resolvers to solve complex trigonometric equations, without the use of isolation amplifiers. They solved such an equation as:

$$A \sin a \cos c + A \cos a \sin b \sin c + B \cos b \sin c$$

This was successfully done, without use of vacuum tubes or amplifiers in this circuit:



In view of the widespread use of resolvers to generate sine and cosine functions in modern electro-mechanical analogue computers, it is of great practical significance. Resolvers produced by the Ford Instrument Company have now reached such a high degree of precision, that it is possible to obtain, from an unloaded resolver (which accommodates a single angular quantity only), an accuracy to within less than one tenth of one percent. But most computing circuits call for the use of several resolvers, and once an ordinary resolver is loaded by another resolver, no matter how high its precision, the overall accuracy of the resolver cascade is seriously affected.

The conventional method of avoiding this difficulty is to use an isolation amplifier for each resolver, so that the resolver continues to operate under no-load conditions regardless of the size of the cascade. The importance of cascading without amplifiers is readily appreciated if we realize that the isolation amplifier usually increases the cost of the equipment, more than doubles the size and generates many times more heat that must be dissipated to prevent breakdown of the components. Furthermore, the use of vacuum-tube amplifiers always raises the problem of tube ruggedness and reliability, and requires an additional source of d-c plate voltage.

Have you problems which the engineers at Ford might solve by designing and manufacturing computers, controls or their elements? Write for further information.



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Division of Sperry Rand Corporation

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Ford's capabilities are among the finest in the country



One of the Ford laboratories where a particular design project has called for careful study of resolvers and resolver cascading. Two of the engineers assigned to this project are here checking results. From this work will come one of the new, highly classified weapon systems for the armed forces.



For accuracy and reliability—both vitally necessary in military instruments—experienced machinists must work to fine precision—in the order of .0005 of an inch. Here in one section of the shops of Ford Instrument Company, men are milling parts for an airborne computer.



During the past year Ford Instrument Company has been busy working on many contracts for the U. S. Air Force and the U. S. Navy Bureau of Aeronautics, designing and manufacturing complex computers, controls and their components. For over forty years, Ford Instrument Company has devoted most of its efforts in working for the government to the many problems of weapon controls.

## ... INDUSTRY'S PULSE

taut last year. How will they keep abreast of the new demands?

Inherent in the McGraw-Hill outlook for the U.S. economy in the next five years is a warning to control manufacturers that they will have to shuck aside conservatism if they want to stay ahead of industry. And stay ahead they must . . . if they are to fulfill an estimated increase in unit sales of 50% by 1960. Not far behind control in the estimates of growth in the next five years are the chemical field (40%), electrical power generating equipment (40%), and atomic energy (which is reckoned at 35%, but which may zoom with new developments).

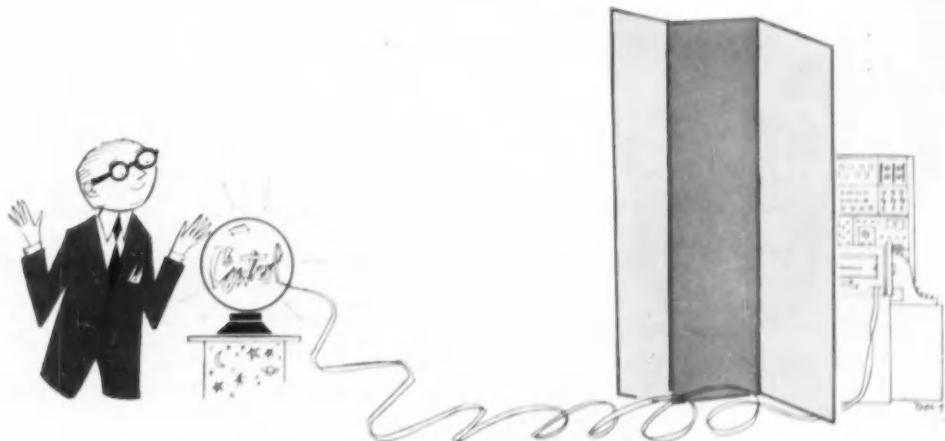
Other industries that are expected to show above-average (20-25%) growth: petroleum, appliances, construction, metal-working. Average growth (15%) will be shown by the trucking and mining industries. And below average growth will occur in food, textiles, and aircraft manufacture.

Only one major market for control is expected to decline in the next decade: defense. This market, now involving \$41 billion for developments and product, is expected to drop to \$36 billion in 1960, \$30 billion by 1965. But, the economists hasten to add, these figures are likely to rise dramatically with any crisis.

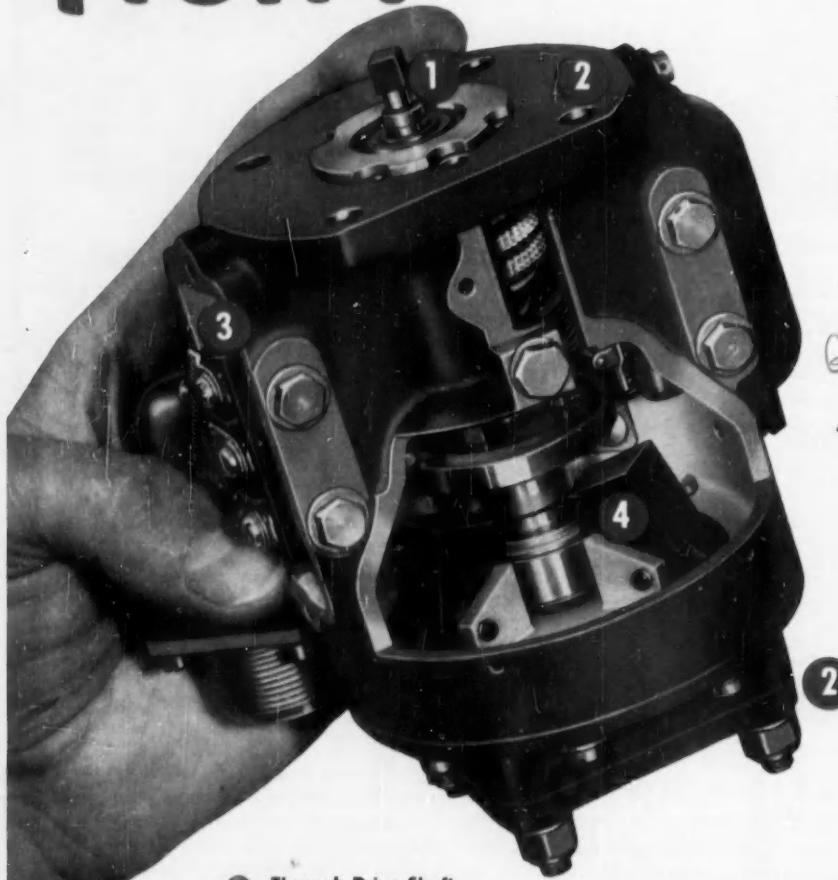
Conclusions that can be drawn from the two surveys can bolster and guide the control engineer in the days ahead. For one thing, he can still count on sizable control activity in such large continuous process industries as chemical and oil, where the outlay for automatic control often approaches 20% of new plant spending. And he can look for almost proportionate gain in emphasis on using control by the other industries as they strive to continuize or "automatize" their operations.

But the fact that he can count on the most—whether he designs control, or puts it to work in the field—is that he'll be rather busy for the next few years. So busy, in fact, that he may have to work 70 hours a week to help bring in the 35-hour work week that industry seems to be headed for.

**As control grows—  
so grows the nation**



# New! AC speed sensing control



- 1 Through Drive Shaft
- 2 Standard AN Drive Pads at both ends
- 3 Snap-Action Switches
- 4 Precision Flyweight Assembly



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# **Interchange**

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# **Fortifies**

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# **Control**

The interchange of control system technology and equipment between military and industry has widened and fortified the base of practice throughout the entire control field. Although the movement has been catalyzed by publication and education, its main spearhead has been the mobility of the control engineer himself.

Today the shuttle of ideas and hardware is predominantly from military to industry. Components such as the electro-hydraulic power control valve, entire sets of mathematical tools for analysis and synthesis, and complete systems of information handling have made the switch. The drift of engineers is less one-sided. A recent questionnaire to a cross-section of our readers roughed-in the dimensions. Of the respondents, one-quarter do solely military control work, two-fifths solely industrial control, and one-third both. One eighth had changed from industry to military and one eighth had moved the other way—a numerical draw but a healthy gain in the spreading of know-how. A whopping majority (three-quarters) of those in military control foresaw an industrial future for their work. They ranked machine control applications first and process control second.

The flow of control people, product, and principles was not always greater to industry. At the start of World War II, designers of ordnance and guidance systems drew heavily on industrial sources. From the steel mill they borrowed the amplidyne generator and the hydraulic positioner. The thyratron came from the resistance welder, the selsyn from synchronizing applications at the Panama Canal, and the highly sensitive pneumatic transmitter and controller from petroleum refining. Each interchange increased our margin of safety in armament. Each will fortify our industrial productivity today.

THE EDITORS

Through dynamic analysis the control engineer strives to optimize control performance and cost. To perform this analysis he must know the dynamic characteristics of each separable part of the complete system. Articles by Reswick (Vol. 2, No. 6) and Reynolds (Vol. 2, No. 10) described how to extract these characteristics from responses to sinusoidal and random disturbances. This article, first in a group prepared by CONTROL ENGINEERING editors from a forthcoming book by Taylor Instrument authors, briefly shows how to derive dynamic characteristics of existing plants by extracting from response to known experimental step disturbance. It then presents a method for calculating the characteristics of a plant that may be in the design stage and works out three plant examples using the method. Subsequent articles will complete the integration of process, transmission elements, and controller into a complete automatic system.

# How to Reckon Basic Process Dynamics

LESLIE M. ZOSS, Taylor Instrument Cos.

Process control improvement requires an adequate knowledge of the dynamic and static characteristics of the system to be controlled. Dynamic characteristics consist mainly of combinations of transfer lags and distance velocity lags. Often in a system study, these characteristics are assumed. How can their actual magnitudes be found?

Two possible approaches are:

**EXPERIMENTAL**—in which the process characteristics are determined directly from the reaction curves that the process variable follows in response to a measurable disturbance, such as a sustained control valve movement. Obviously, this method only applies to existing processes. It is used a great deal in trouble-shooting.

**ANALYTICAL**—in which the dynamic characteristics derive from equations representing energy or mass balance. This method can be applied to an existing process as well as to one that is in the design stage.

## THE EXPERIMENTAL METHOD

Time constants can be extracted from step response data by the per cent incomplete response technique

shown here. This technique involves the evaluation of linear transfer lags.

### Single Linear Transfer Lag

The response to a step change disturbance of a single linear lag is shown by the solid line of Figure 1. Here, at any time  $t$ , the curve designates the per cent complete response. Then the per cent incomplete response,  $b$ , is found by subtracting  $a$  from 100 per cent, and  $b$  equals  $100-a$ . Since the time constant equals the time of 63.2 per cent of the complete response, it also equals the time of 36.8 per cent of the incomplete response.

If this per cent incomplete curve is plotted on a logarithmic scale and time on a linear scale, a straight line (Figure 2) results. As in Figure 1, the coordinates are non-dimensional so that the information will not be restricted to the actual magnitude of the time constants under consideration. Figure 2 shows that the time constant equals the time of 36.8 per cent incomplete response (36.8 per cent at  $IT$ ).

### Two Series-Connected Linear Lags

Suppose that step response data have been obtained through an experimental run on a different

**RESPONSE  
CURVES  
YIELD LAG  
MAGNITUDES**

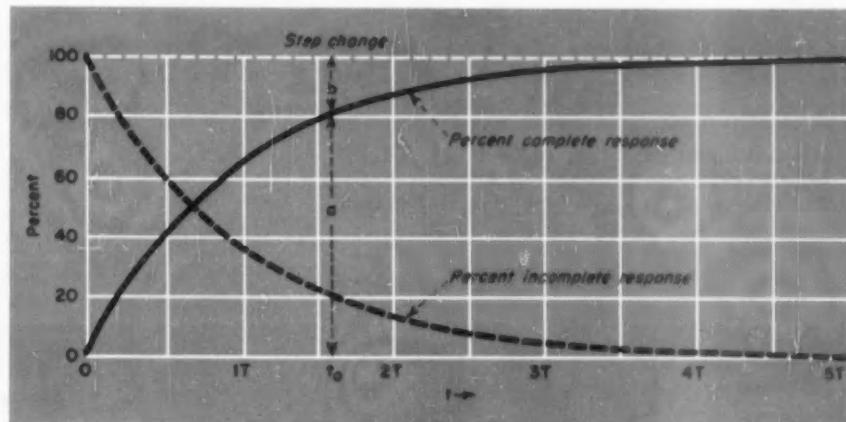


FIG. 1. The solid line represents the reaction curve of a single linear lag process. The reaction curve is also called the per cent complete response, and at time "t" it equals "a" per cent complete. The per cent incomplete response, the dashed line, is the difference between 100 per cent and the per cent complete, or  $b$  equals  $100-a$  per cent. The time constant,  $T$ , of the process equals the time for 36.8 per cent incomplete response.

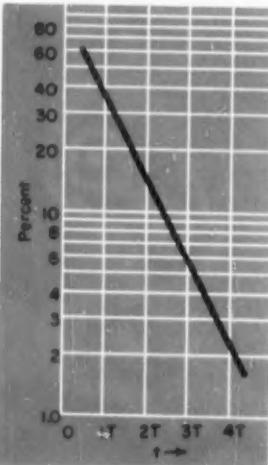
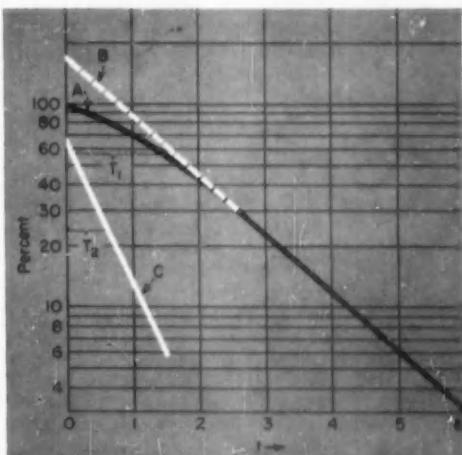


FIG. 2. Here, the per cent incomplete response characteristic has been replotted on a logarithmic scale for magnitude against linear time scale. The advantage of this new plot is a straight line for the reaction.

FIG. 3. In this graph, the per cent incomplete response (Curve A) for two series-connected linear lags has been plotted directly on semi-logarithmic paper. The straight-line portion of Curve A extends back to the zero time axis, giving Curve B. The larger of the two time constants can then be obtained from Curve B. The difference between Curves A and B is plotted as Curve C, from which is computed the second time constant. See the text for the exact procedure in computing the time constants.



system. Then, it may be possible to determine whether this system can be represented, with reasonable accuracy, by two time constants. If these time constants are not nearly equal, they can be found by the per cent incomplete response method.

Curve A of Figure 3 represents the per cent incomplete response for a typical two-series connected linear lag system. If accurate data are obtained for large values of time, the linear portion of this curve is extended straight back to the zero time ordinate, developing Curve B. To determine the larger time constant  $T_1$ , read the vertical intercept of Curve B, 1.67, and take 36.8 per cent of this value, which equals 61.5 per cent. The time constant  $T_1$  is equal to the time when Curve B has an ordinate of 61.5 per cent. Thus, in this case  $T_1$  is 1.5 min. So far, this method is similar to that for finding the time

constant of a single linear lag, described above.

Now to find the value of the second time constant,  $T_2$ , plot Curve C, the difference in values between Curve B and Curve A. (If these differences do not plot as a straight line, the system cannot be represented as two series-connected lags.) Curve C intercepts the zero time ordinate at 0.67, and 36.8 per cent of 0.67 equals 24.6 per cent. Then, the time constant  $T_2$  equals the time when Curve C has an ordinate of 24.6 per cent, which is 0.6 min.

It is theoretically possible but not practical to repeat this procedure with more time constants.

### THE ANALYTICAL METHOD

The analytical method determines processes characteristics by calculation. For instance, physical

constants and the geometry of a temperature-controlled process establish the parameters for a heat balance. This heat balance, a transient condition, gives time constants as direct answers.

The rate of heat flow in equals the sum of the rate of outward heat flow and the rate of heat flow into thermal storage. Thus, in a heat balance, the basic equation is:

$$Q_{in} = Q_{out} + Q_{storage}$$

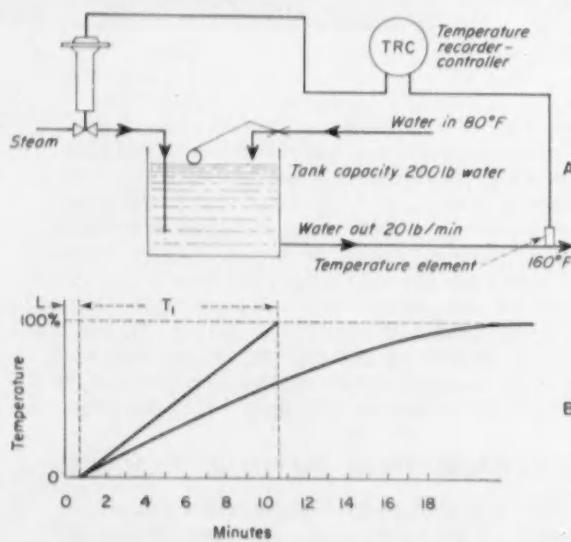
where  $Q$  equals the rate of heat flow in Btu/min.

### PROCESS I: TEMPERATURE CONTROL —SINGLE LINEAR LAG

Figure 4 illustrates a typical system having a single linear lag plus distance velocity lag. A sudden and sustained pressure change at the steam valve operator will cause the process to unbalance and seek a new balance at a different final temperature. Just how the process reacts is shown in Figure 4B. The distance velocity lag ( $L$ ), as read from this curve, is 0.6 min. The time constant  $T_1$ , or 63 per cent response time, is about 10 min. Thus, the values of the desired characteristics have been found.

But suppose the system was in the design stage. The procedure then is somewhat different, for physical constants of the system must be known to determine analytically the characteristics of the process. Thus, for Figure 4A, the following are known:

FIG. 4. A temperature control process, which has one time constant and a distance velocity lag, is shown in Figure 4A. From its reaction curve, Figure 4B, the value of the distance velocity lag and the single time constant may be obtained. These same results can be computed on an analytical basis from the data in Figure 4A.



|                                     |           |
|-------------------------------------|-----------|
| water in tank.....                  | 200 lb    |
| water in line between tank and bulb | 12 lb     |
| water flow .....                    | 20 lb/min |
| steam flow (maximum).....           | 6 lb/min  |
| incoming water temperature.....     | 80 deg F  |
| outlet water temperature.....       | 160 deg F |

### Distance Velocity Lag

The distance velocity lag is the time it takes the temperature element to sense a change in temperature in the tank. Therefore, for the system above, the distance velocity lag ( $L$ ) equals

$$\frac{12 \text{ lb}}{20 \text{ lb/min}} = 0.6 \text{ min.}$$

### Time Constant

To determine the time constant of this process go back to our basic balance equation:

$$Q_{in} = Q_{out} + Q_{storage} \quad (1)$$

where  $Q$  is the rate of heat or energy flow.

For a 3-15 psi stroke of the steam valve the steam flow change is 6 lb/min, or  $\frac{1}{2}$  lb/min/psi if the valve is assumed to be linear. Now, a change of  $m$  psi at the steam valve operator results in a rate of energy added to the system:

$$Q_{in} = 1/2 \text{ lb/min/psi} \times m \text{ psi} \times 1000 \text{ Btu/lb} \quad (2)$$

$$= 500 m \text{ Btu/min}$$

where 1000 Btu/lb is the latent heat of the steam.

The rate of energy leaving the system may be found as follows:

$$Q_{out} = 20 \text{ lb/min} \times 1 \left( \frac{\text{Btu}}{\text{lb } ^\circ\text{F}} \right) \times (\theta_1 - 160) ^\circ\text{F} \quad (3)$$

where  $\theta_1$  = final temperature in  $^\circ\text{F}$  of tank 1, and  $1 \frac{\text{Btu}}{\text{lb } ^\circ\text{F}}$  is the specific heat of water.

Under equilibrium conditions the water in the system and the water leaving the tank is at 160 F. Thus, the final tank temperature after a change of  $m$  psi is  $\theta_1$  equals  $(160 + \theta)$  deg F, where  $\theta$  is the temperature change resulting from the addition of steam. With this change in variable, Equation 3 can be rewritten as

$$Q_{out} = 20 \text{ lb/min} \times 1 \left( \frac{\text{Btu}}{\text{lb } ^\circ\text{F}} \right) \times \theta ^\circ\text{F} \quad (3a)$$

The rate of energy stored, assuming instantaneous mixing of the feed water, is

$$Q_{storage} = 200 \text{ lb} \times 1 \left( \frac{\text{Btu}}{\text{lb } ^\circ\text{F}} \right) \times \frac{d\theta_o}{dt} \frac{^\circ\text{F}}{\text{min}} \quad (4)$$

The derivative of  $\theta_o$  with respect to time results in  $d\theta_o/dt$ , since

$$\frac{d\theta_o}{dt} = \frac{d(160 + \theta)}{dt} = \frac{d(160)}{dt} + \frac{d(\theta)}{dt} = 0 + \frac{d\theta}{dt}$$

Equation 4 may now be written as

$$Q_{\text{storage}} = 200 p \theta \quad (4a)$$

where  $p = d/dt$ , the Heaviside operator.

Substituting Equations 2, 3a, and 4a into Equation 1,

$$500m = 20\theta + 200p\theta, \text{ or}$$

$$\frac{\theta}{m} = \frac{25}{(1 + 10p)} \quad (5)$$

Equation 5 is a linear first order differential equation with constant coefficients. From the term  $(1 + 10p)$  we see that the time constant  $T_1$  equals 10 min. Thus, the analytical method verifies the values of  $L$  and  $T$ , obtained from the reaction curve.

## PROCESS II: TEMPERATURE CONTROL —DOUBLE LINEAR LAG

Adding another tank to the previous system complicates the process. Figure 5 shows this new system and its reaction curve. Here, the distance velocity lag has been eliminated by placing the temperature sensing element in the second link. The S-shaped reaction curve indicates the process has more than one time lag.

The time constants can be determined from the reaction curve by the incomplete response method. Evaluation by this procedure will show that the system can, indeed, be expressed by two time constants. These values are  $T_1$  equals 10 min, and  $T_2$  equals 5 min.

Now, if it is assumed that this process is in the design stage, then the information shown in Figure 5 aids in finding the time constants. Note that the conditions of the first tank of this system are the same as those in the first example.

The transient energy balance of the system is given by:

$$Q_{\text{in}} (\text{Tank 1}) = Q_{\text{out}} (\text{Tank 1}) + Q_{\text{storage}} (\text{Tank 1}) \text{ and} \quad (6)$$

$$Q_{\text{in}} (\text{Tank 2}) = Q_{\text{out}} (\text{Tank 2}) + Q_{\text{storage}} (\text{Tank 2}) \quad (7)$$

Note that  $Q_{\text{out}} (\text{Tank 1}) = Q_{\text{in}} (\text{Tank 2})$ .

The rate of energy leaving tank 2 is

$$Q_{\text{out}} (\text{Tank 2}) = 20 \frac{\text{lb}}{\text{min}} \times 1 \frac{\text{Btu}}{\text{lb F}} (\theta')^{\circ}\text{F} \quad (8)$$

where  $\theta' = \text{temperature change of tank 2 in deg F}$ , or  $\theta' = (\theta_2 - 160) \text{ F}$ .

The rate of energy stored in tank 2 is:

$$Q_{\text{storage}} (\text{Tank 2}) = 100 \frac{\text{lb}}{\text{min}} \times 1 \frac{\text{Btu}}{\text{lb}} \times \frac{d\theta'}{dt} \frac{\text{deg F}}{\text{min}} \quad (9)$$

$$\text{or } Q_{\text{storage}} (\text{Tank 2}) = 100 p \theta' \quad (9)$$

Substituting Equations 3, 8, and 9 in equation 7 gives,

$$20 \theta = 20 \theta' + 100 p \theta' \text{ or} \\ \theta = \theta' + 5 p \theta = \theta' (1 + 5 p) \quad (10)$$

Now, from Equation 5

$$\theta = \frac{25 m}{(1 + 10 p)}, \text{ so that Equation 10 becomes}$$

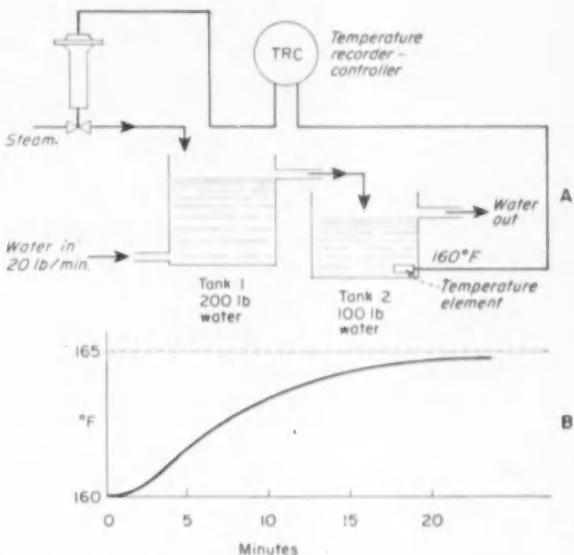


FIG. 5. Figure 5A shows another temperature control process, but this one has two tanks that create two time constants. The typical S-shaped reaction curve, Figure 5B, tells that there is more than one time constant. Like the data in Figure 4A, that in Figure 5A may be used to compute the values of the two time constants.

$$\theta' (1 + 5 p) = \frac{25 m}{(1 + 10 p)} \text{ or}$$

$$\frac{\theta'}{m} = \frac{25}{(1 + 10 p)(1 + 5 p)} \quad (11)$$

From this result the time constants are obtained; namely  $T_1$  equals 10 min and  $T_2$  equals 5 min. These values confirm those obtained from evaluation of the reaction curve in Figure 5B.

## PROCESS III: PRESSURE CONTROL —SINGLE LINEAR LAG

The control of pressure is an interesting illustration of another example of the procedure for finding process characteristics. Proper analysis of the system in Figure 6 requires that the load effects be taken into account.

To do this we must have the static curves of tank pressure,  $P_t$ , versus air flow,  $Q$ , out of the tank for various load pressures  $P_L$ . Curves of this type, assuming linear conditions, are shown in Figure 7. Although these curves probably would not be obtained in an actual system, the assumption of small changes around any chosen operating point upholds the linearity requirements. However, if the operating point is unknown then the limiting conditions of the process operation, in this case the load resistance, must be considered. From the slopes of the load pressure curves of Figure 7, note that the load resistance varies between the limits of 5 psi/lb/min (for

load pressure curve  $P_{L1}$ ) to infinity when  $Q$  equals zero. The variations must be considered in the analysis.

For transient mass balance conditions

$$Q_{in} = Q_{out} + Q_{storage} \quad (12)$$

where  $Q$  = air flow, lb/min.

A sudden change of  $m$  psi at the valve operator creates a step change at the input of the system. Since a 12 psi change at the valve input causes the load flow to go from 0 to 10 lb/min, the relationship becomes

$$Q_{in} = 0.83 \frac{\text{lb/min}}{\text{psi}} \times m \text{ psi} \quad (13)$$

Now, if it is assumed that the operating point lies on  $P_{L1}$  and that the tank equilibrium pressure is 50 psi, then the following obtains:

$$Q_{out} = \frac{10 \text{ lb/min}}{50 \text{ psi}} (P_t - 50) \text{ psi} = \frac{P_o}{5} \frac{\text{lb}}{\text{min}} \quad (14)$$

where  $P_t$  = total tank pressure, and  
 $P_o$  = change in tank pressure.

The rate of change of air stored in the tank becomes

$$Q_{storage} = \rho \frac{V}{P^*} \frac{dP_t}{dt}, \text{ or}$$

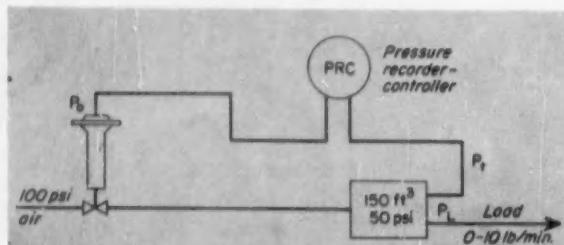


FIG. 6. The pressure control system above represents another single linear log process. But here the load pressure,  $P_L$ , affects the value of the time constant, which depends on the operating point, as shown in Figure 7.

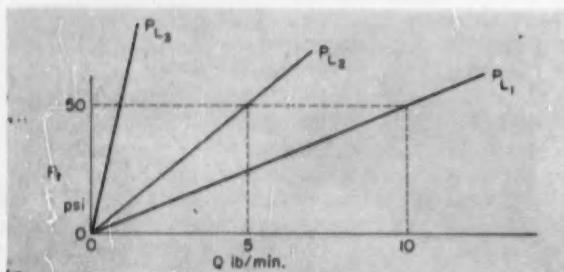


FIG. 7. For a given tank pressure,  $P_t$ , the air flow,  $Q$ , out of the tank depends on the value of the load pressure,  $P_L$ . Therefore, dynamic analysis of the system in Figure 6 requires that the operating point be fairly constant or that the worst possible condition be used in computing the necessary controller characteristics.

$$Q_{storage} = \rho \frac{V}{P^*} \frac{d(P_o + 50)}{dt} = \rho \frac{V}{P^*} p P_o \frac{dP_o}{dt} \quad (15)$$

Again, the operational form of the derivative simplifies the calculations, so that  $Q_{storage} = \rho \frac{V}{P^*} p P_o$  (15)

where  $\rho$  = specific weight of air, 0.076 lb/ft³

$V$  = tank volume, 150 ft³

$P^*$  = atmospheric pressure, 14.7 psi.

Thus

$$Q_{storage} = 0.77 p P_o \quad (15a)$$

Substituting Equations 13, 14 and 15a in Equation 12 yields

$$0.83 m = -\frac{P_o}{5} + 0.77 p P_o \quad (16)$$

Equation 16 reduces to the familiar form for a transfer function

$$\frac{P_o}{m} = \frac{4.15}{1 + 3.85 p} \quad (17)$$

from which it is seen that the time constant equals 3.85 min. When  $p$ , the frequency dependent term, is zero then the zero frequency gain equals 4.15. This gives one limit of our process operation.

But, if the above procedure is carried out for a different operating point, say  $P_{L2}$ , then the resulting transfer function is

$$\frac{P_o}{m} = \frac{8.3}{1 + 7.7 p} \quad (18)$$

Here, the time constant equals 7.7 min and the zero frequency gain is 8.3.

Equations 17 and 18 show the generalized form of the transfer function for this process to be:

$$\frac{\text{output}}{\text{input}} = \frac{K T}{1 + T p} = \frac{K}{1/T + p}$$

where  $K$  equals 1.08 for this particular system.

In the extreme situation, when load resistance goes to infinity,  $T$  also approaches infinity and the transfer function becomes  $K/p$ . This is the other limit of the process operation.

A frequency response plot of the above pressure process leads to some interesting conclusions. But before reaching these conclusions, it is necessary to assume some reasonable values of time constants and zero frequency gains for the valve and measuring circuit. For the valve the time constant is 0.15 min and the zero frequency gain is unity. For the measuring circuit transmitter the time constant is 0.10 min. And its zero frequency gain is 0.12, because the output varies 12 psi for 100 psi input.

Figure 8, the frequency response plot, describes the characteristics for the individual components. Dashed lines represent the control valve, measuring circuit, and three different values of  $T$  for the process; and solid lines the overall response of the complete system. The phase shift diagram shows that the system phase lags 90° at some frequency less than 1 cpm, regardless of the time constant of the process.

Now, an acceptable phase margin of 30°

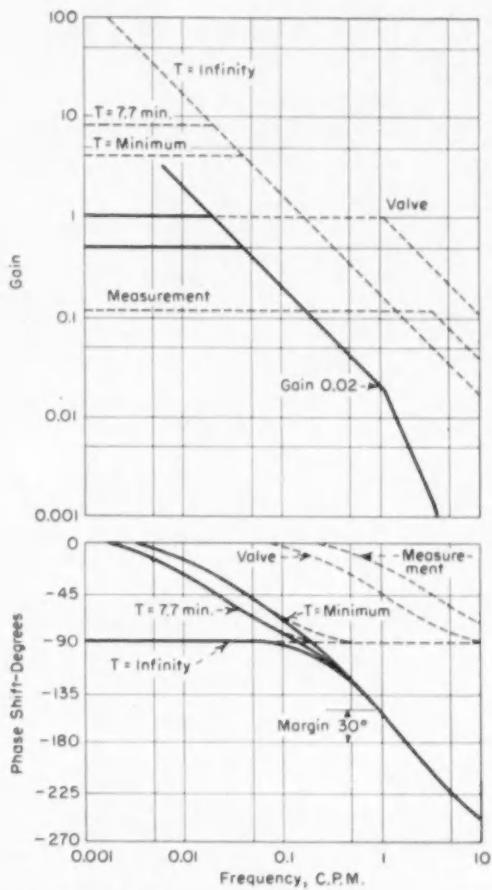


FIG. 8. This frequency response plot for the system of Figure 6 shows that the overall system gain, for stable operation of the process, is the same regardless of the particular operating point (and hence time constant) of the tank.

occurs at about 1 cpm, and at this frequency the overall process gain is 0.02. Thus, a controller gain of  $1/0.02$ , or 50, assures stability of the system. This controller gain results in a fixed value regardless of the size of the process time constant. But some economic benefit may accrue if the system can be designed for a smaller tank. What, then, are the controller requirements and their effect on the overall system?

Suppose that the tank volume has been cut to a point where its time constant is reduced by a factor of ten, as compared with the original system. The corresponding frequencies thus increase by the same factor of ten. The characteristics of the control valve and measuring circuit remain as before. Figure 9 shows the frequency response of the overall system.

Here the 30 deg phase margin occurs at frequencies dependent on the particular time constant of the process; and thus the corresponding process gains

differ. Now, the product of process and controller gains should not exceed unity for a stable system. The highest value of process gain, 0.2, occurs at infinite  $T$ , and this should be used in calculating the controller gain. Therefore, controller gain equals  $1/0.2$  equals five.

Thus, by reducing tank size the allowable controller gain has been decreased by a factor of ten. This situation could create a difficulty in that excessive offset error may occur following load changes. Therefore, an additional controller mode, say reset, might be necessary to compensate for this offset.

The plant examples used above are based on *Process Lags in Automatic-Control Circuits*, J. G. Ziegler and N. B. Nichols, Trans. ASME, Vol. 65, 1943.

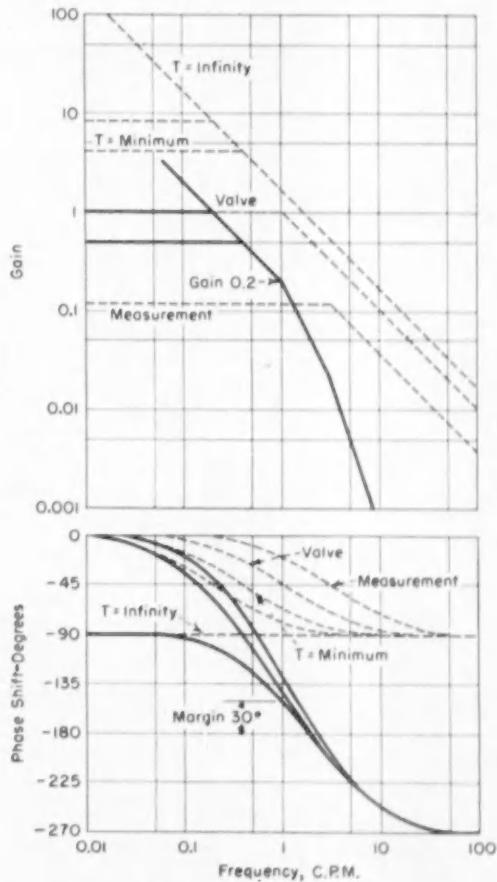


FIG. 9. When the time constants of Figure 6 are reduced by a factor of ten, the frequency range for the tank response increases by the same factor. But now the overall phase shift curves differ at the phase margin frequencies. Therefore the process gain—and the controller gain—differ for each value of the process time constant. Thus, the conservative (highest) value of process gain, equal to 0.2, assures stable operation regardless of the operating point.

# Four Steps to Practical Machine Tool Control

1. ANALYZE OPERATIONS
2. GROUP FUNCTIONS
3. LAY OUT CIRCUIT
4. ADD MANUAL CONTROL

T. C. CAMERON, Sundstrand Machine Tool Co.

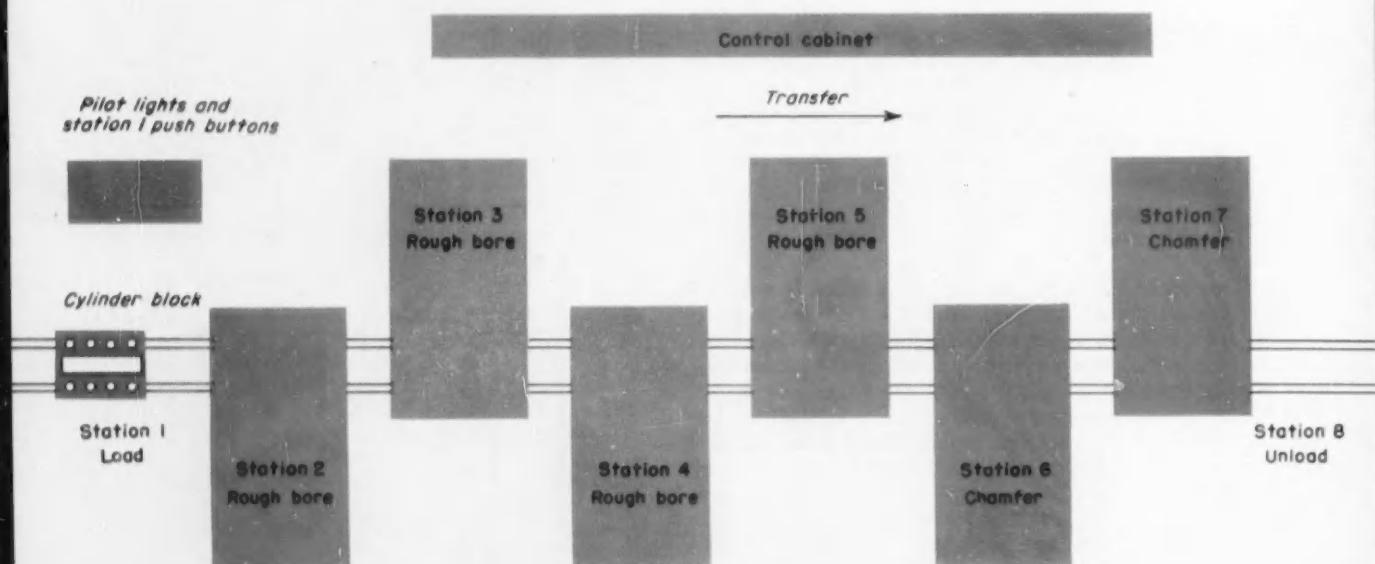


FIG. 1. Schematic diagram of six-head transfer machine shown in Figure 2.

FIG. 2. Rough boring unit of an automatic line for engine blocks.

**THE GIST:** The majority of machine tool operations can be done most cheaply with straight-line motion at constant feed rates. This indicates magnetic control, limit switches, and squirrel cage motors, combined to form a system that will cause the machine to go through its functions in the proper sequence.

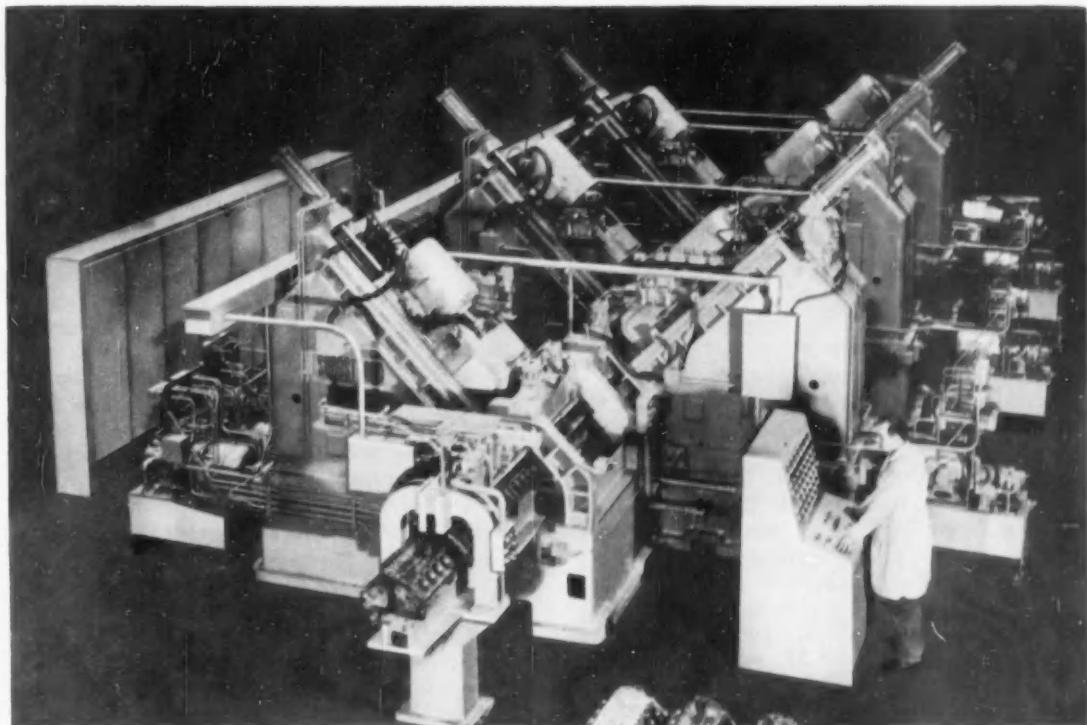
The design of this type of system can be simplified by a logical series of steps that applies, with minor variations, to any sequential control. In the first step, machine operation is analyzed and a cycle diagram set up for the entire machine. The overall machine functions are organized in step two into logical groups of control circuits. In step three the individual group control circuits and interlocks between groups are designed. And finally, the control system is modified to permit manual control. With the transfer machine in Figure 2 as an example, this article tells how to apply this technique.

Figure 1 shows schematically the cylinder block line pictured in Figure 2. This integral group automatically machines, transfers, and loads and unloads when conditions permit. The cylinders are rough-bored two at a time in four stations, and chamfered in the last two stations.

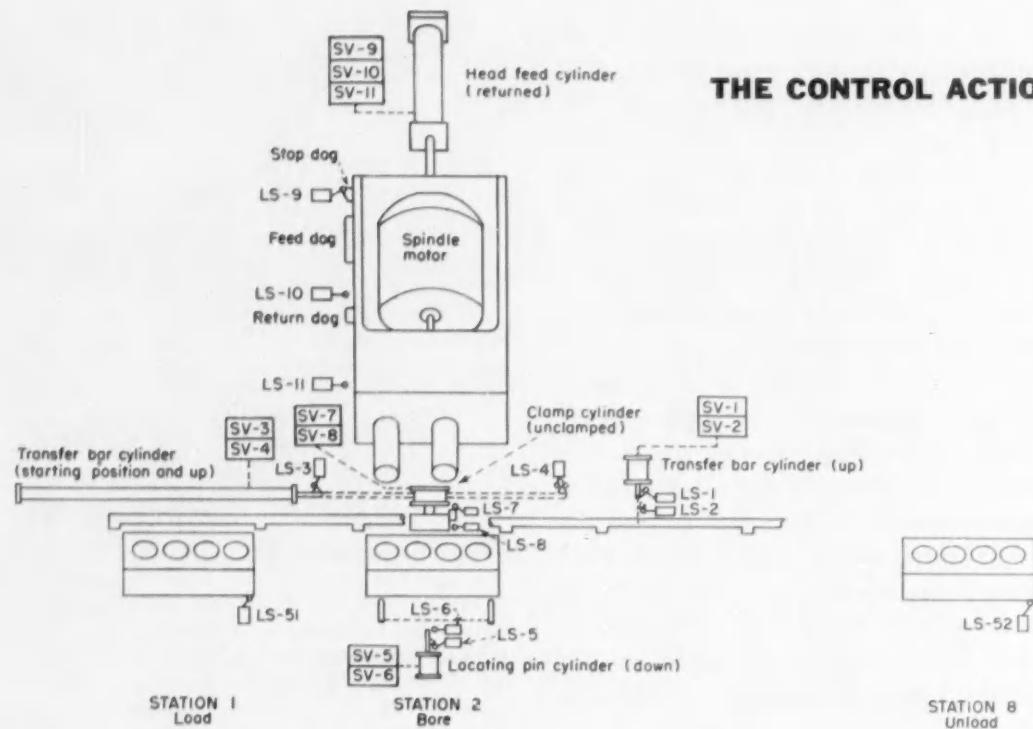
The control system performs three basic functions: control of the moving elements; indication of position of the machine elements; and protection of the machine, the operating personnel, and the control itself. Since a production line may be several hundred feet long and may have only a few operators, machine operation and safety depend exclusively on control. Easy maintenance is important, since there are hundreds of possible points for trouble and "down time" is expensive. Thus control circuits should be as simple and direct as possible and local indicator lights should be used liberally.

## 1. ANALYZE MACHINE OPERATIONS

The first requirement is thorough familiarity with the machine itself and the conditions under which it will be operated. Determine the sequence of all movements necessary to complete a cycle. Which ones can or must be operated independently, and which can be grouped to operate as a unit? The necessary push buttons and indicator lights can be approximated and all driving means noted. This in-



## THE CONTROL ACTION . . .



cludes the motions controlled by hydraulic solenoid valves.

Figure 3 shows stations 1, 2, and 8 and the transferring mechanism. The transfer bar extends the full length of the machine to simultaneously transfer all parts to the next station.

The mechanical cycle is as follows:

- transfer bar lowers to engage work
- transfer bar advances, moving each part to the next station
- locating pins in each fixture rise
- clamps lower to secure part
- transfer bar raises, then returns; simultaneously, all heads start rapid approach
- heads feed individually
- heads rapid return individually
- locating pins drop and clamps rise
- cycle repeats if new part is available and the finished one has been removed from the unload station.

The total machine cycle can be reduced to groups of motions. The transfer cycle is a group; down then forward is the first half and up then return the second half. Each fixture is a group, and each head another group. Each head must rapid approach, feed, and rapid return when its fixture is clamped.

A group of indicator lights for each station is convenient for showing the following: motors running, cycle on, cycle completed, fixture clamped, and fixture unclamped. Lights can also show the

transfer bar position and the condition of the load and unload stations.

### Limit Switches

An important part of the machine analysis is locating the limit switches for the particular cycle. A limit switch is required at each end of each motion, and at any other point where a machine member stops, changes rate, or starts another motion. The switches should be mounted so that their operation is not affected by motions other than the one they are to detect. Thus, every significant position of the machine can be detected and any physically possible sequence controlled. The limit switches convey machine information to the control, where it is stored until a particular group of motions is completed. Then the proper combination of relays starts the next motion in the sequence.

When the above information has been collected it is usually convenient to arrange it graphically in a cycle diagram or in a reference table. Figure 4 shows a cycle diagram for the whole machine. Figure 3 is a mechanical display of about the same information for station 2.

The solenoid valves are located on the cycle diagram alongside the motions that result when the solenoids are energized. The limit switches are placed to show the time they are operated during a particular motion. For example, station 2 head

## ... AND ITS CYCLE DIAGRAM

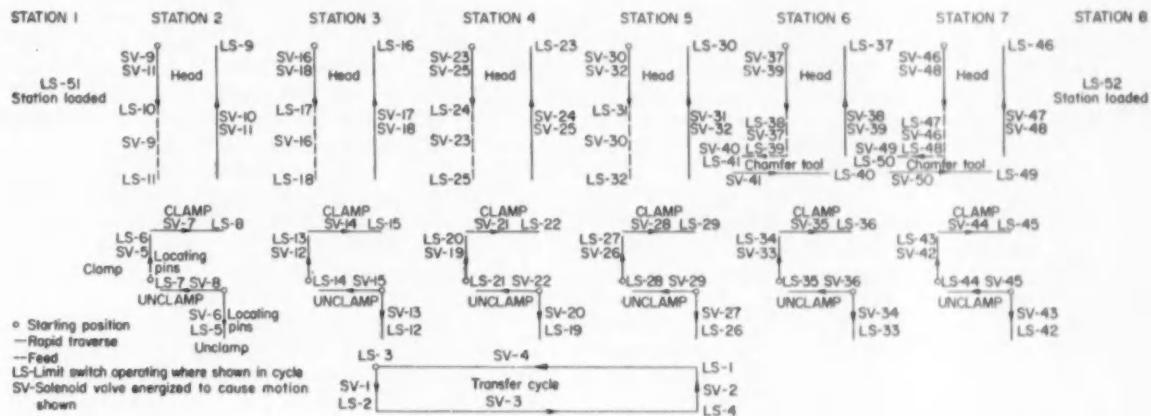


FIG. 3. Detailed schematic of stations 1, 2, and 8, showing all control components. Since other five work stations are similar, this represents the whole machine.

rapid approaches when SV-9 and SV-11 are energized. Limit switch LS-10 de-energizes SV-11 and the head feeds to the end of the stroke. At this point, LS-11 is actuated, energizing SV-10 and SV-11. Then the head rapid returns to LS-9, which de-energizes SV-10 and SV-11 to stop the head.

To summarize the first step in the design procedure: collect all the information about the machine and coordinate it as shown in Figure 4.

## 2. GROUP MACHINE FUNCTIONS AND CONTROL CIRCUITS

The second step in designing a control system for a machine of the type under discussion is to determine the general arrangement of the control, Figure 5. Transferring, work handling, lubrication, chip conveyors, etc., are common to all working stations and make a convenient control group. In addition, each working station becomes a separate control group.

Next, each working station group must be interlocked with the common or transferring group. Thus interlocked, each working group requires from the common group a signal that transferring is complete before it can start a machining cycle. Also, when the cycle ends, a signal must be sent from every station before transferring can begin.

For example, at the end of the station 2 cycle (Figure 6B), CR-11 is released and CR-7 and CR-9

FIG. 4. Cycle diagram for entire machine. Shows all machine motions plus the control components that cause and are actuated by these motions.

are closed. CR-11 and CR-9 assist in latching CR-5, Figure 6A, and CR-5 and CR-7 must be closed to transfer. Then, at the end of the transfer stroke, LS-4 energizes CR-4, Figure 6A. In Figure 6B a CR-4 contact latches CR-11 and releases CR-12 to clamp and start the station 2 machining cycle.

Each group can then be built on a reasonably sized panel and can have a separate diagram that requires a minimum of reference to other panels. This simplifies the building and servicing of the equipment.

## 3. DESIGN DETAILED CIRCUIT

This third step consists of laying out a circuit with the appropriate relays for the desired automatic sequence. The following approach is based on complete electrical control.

Most of the relays and their functions can be determined before starting the circuit design. They can be divided into three categories: those that provide additional contacts (energized only by limit switches); those for starting and stopping (usually push-button-operated in a three-wire circuit), and those that are mechanically latched.

### Three-Wire Control

Three-wire circuits for running motors and effecting cycles should be worked into a circuit first, in

conjunction with the proper overload and short circuit protection. "Safe failure" must also be provided.

Figures 6A and 6B show the common control group and the control for station 2. The other stations are identical to station 2 except that the chamfering stations have one additional motion. Thus Figure 6 covers the whole machine in principle. The circled number at the push buttons indicates the station where the button is mounted.

The motors are started and protected in groups; see *H1*, *H2* and *CR-A* in Figure 6A, and *S*, *H*, and *CR-E* in Figure 6B. The fixture motors must be started first to provide clamping (if required). Then other motions can start. Relay *CR-A*, energized when the fixture and transfer motors are running, has a contact in each station to indicate this condition. A single master stop button stops the whole machine; so does the failure of a fixture motor. Wedge type clamps sustain clamping pressure, even if a fixture motor stops in the clamped position.

If *CR-A* is energized, and the "control" selector switch is on Automatic, *CR-G* is energized and the station 2 motors can be started from either station 1 or station 2. If it is on manual, the motors can be started from station 2 only. Thus station 2 can run without the danger of the motors starting unexpectedly from station 1. The station 2 motors can be stopped by the push button or the overload relays without affecting the other stations. If this happens during an automatic cycle, the other stations continue to the end of their cycles. But then the machine will not transfer, since one station hasn't completed its cycle.

*CR-B* and *CR-F* are cycle control three-wire relays. Relay *CR-B*, in Figure 6A, allows the transfer bar to be stopped at any time but re-started only if the other machine conditions are satisfactory.

The transfer solenoid valves, *SV-1*, 2, 3 and *SV-4*, are energized by a *CR-B* contact, thus permitting *CR-B* to override the automatic control of the bar.

*CR-F* is the cycle relay for station 2, Figure 6B. If this relay is in its normal energized position, station 2 cycles automatically when it is loaded with a new part. Then, with *CR-F* energized and de-energized by cycle start and stop buttons, the motors and spindle can run while the cycle is stopped and re-started. Also, each station can start individually after a new part has been loaded into the fixture. This flexibility is not required in normal daily operation, but is a convenient feature during "down time".

The master cycle-start and cycle-stop buttons energize relays *CR-C* and *CR-D*, Figure 6A, to control all cycles simultaneously by contacts in each station.

In normal operation, all cycle relays—*CR-B*, *CR-F*, and their counterparts in the other stations—remain energized after starting. Then, whenever all the cycles are finished, the unload station is empty, and the load station is full, the cycle repeats automatically. The above three-wire controls are the framework into which the sequencing control is fitted.

### Latching Relays

Latching relays are used to determine the direction of moving elements and as "memory" devices. For example, a head may run through a cycle and return, leaving all machine elements in the same place they were when the cycle started. A relay latched or released at the end of the cutting stroke is one way of indicating the head has run. And in the case of power failure or machine stoppage, latching relays can "remember" what has run previously and their direction of motion when stopped.

Relays can control machine functions singly or

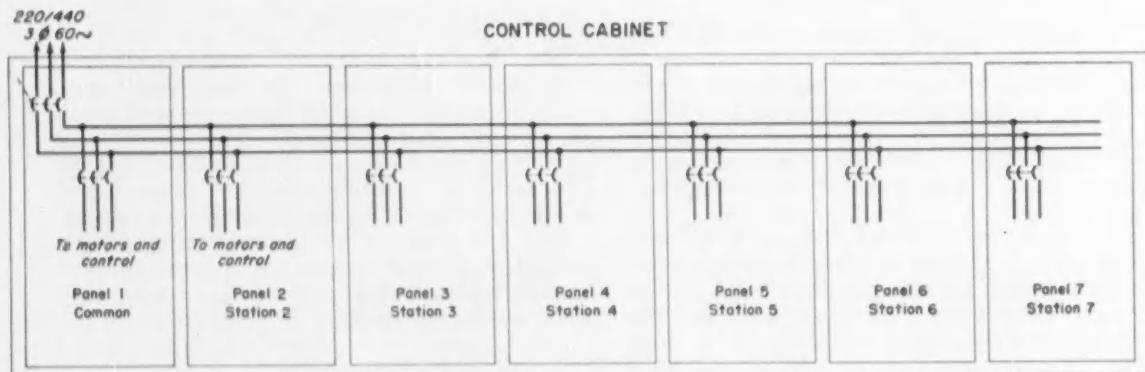


FIG. 5. Typical control cabinet arrangement for multi-station transfer machine.

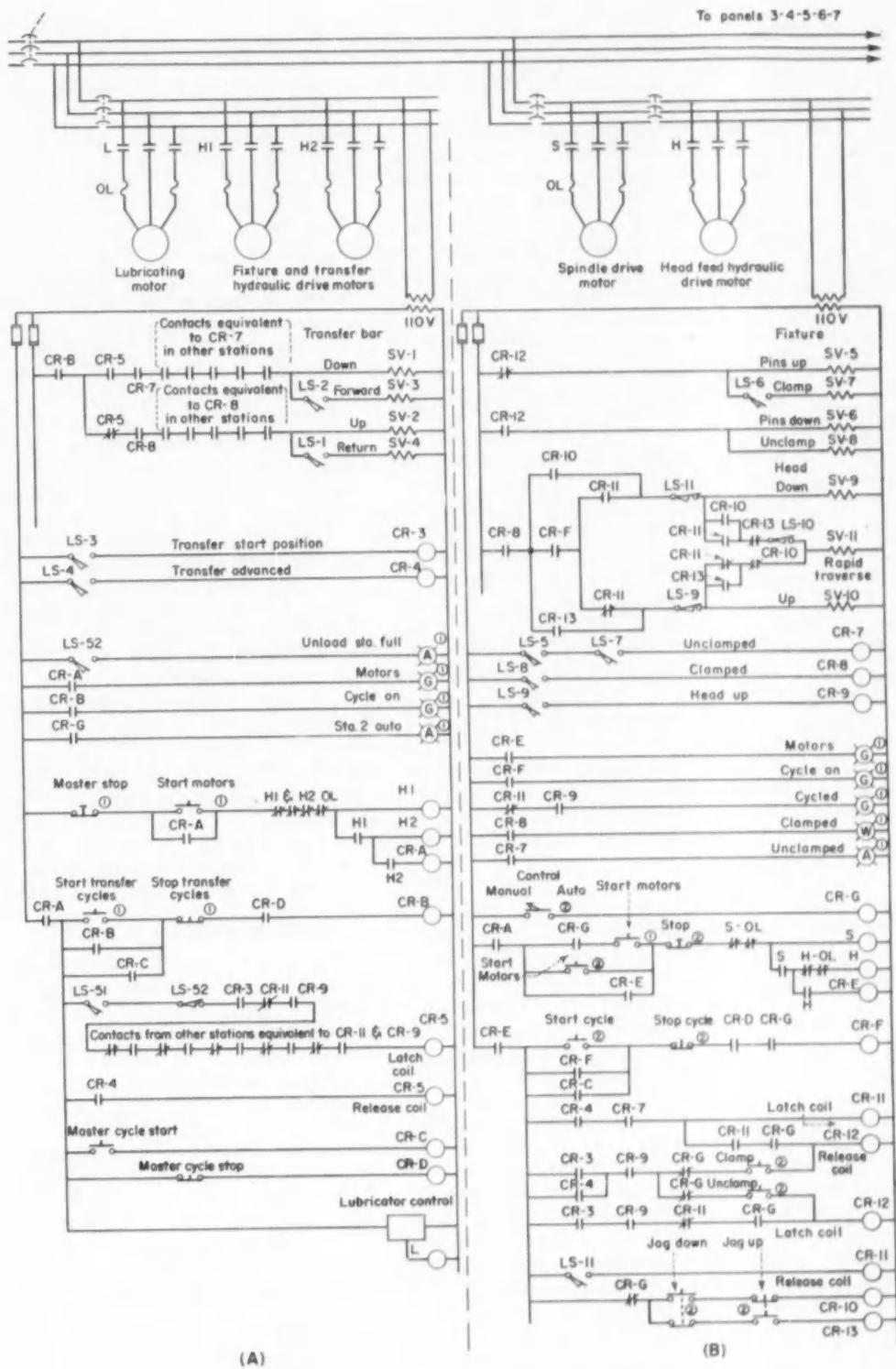


FIG. 6. Elementary wiring diagram for two control groups. (A) shows the circuit for the common station 1, while (B) shows the circuit for the first boring station, station 2.

in groups, depending on the required flexibility. Then the circuit is simplified to a process of latching and releasing relays at the proper times. This is the basis for the control, and should be as simple and direct as possible.

There are three major elements in this transfer machine: the transfer mechanism, the heads, and the fixtures. These are related to each other in the same way in each station, so that a single latching relay can be assigned to control each.

Relay CR-5, Figure 6A, controls the group of motions for the transfer cycle. When latched, this relay energizes SV-1 to drop the bar to LS-2, which in turn energizes SV-3 to advance it. When CR-5 is released, SV-2 is energized to raise the bar to LS-1, which energizes SV-4 to return it.

Relay CR-12, Figure 6B, in the released position energizes SV-5 to raise the locating pins to LS-6, which energizes SV-7 to clamp the fixture. The fixture is unclamped by latching CR-12, which energizes SV-6 and SV-8.

When relay CR-11 is latched, SV-9 and SV-11 are energized, causing the head to rapid approach to LS-10. A dog holds LS-10 open, causing the head to feed to LS-11, which releases CR-11. This energizes SV-10 and SV-11 for rapid return to LS-9. This limit switch opens to de-energize SV-10 and SV-11.

CR-11 serves as a "memory" relay as well as to determine head direction. It is latched when a new part has been loaded; this is indicated by the transfer bar being forward and the fixtures being unclamped. The transfer must not run again until this part has been machined, and this can be assured by interlocking with CR-11 and CR-9, since CR-11 is released only at the end of a machining stroke and CR-9 is energized when the head is up. Thus a combination of a NC contact from CR-11 and a NO contact from CR-9 indicates that the head has run, since a new part was loaded into the fixture. The latching of CR-5 to run the transfer is dependent on this combination existing at each station. In Figure 6B, the same combination is used to latch CR-12 to unclamp the fixture.

The circuit design problem is now reduced to operating CR-5, CR-11, and CR-12 in sequence, and adding contacts directly in the solenoid valve circuits to provide additional safety for, and manual control of, the transfer machine.

The transfer bar must drop and advance only under these conditions: the cycle is on (CR-B), the bar is at the starting position (CR-3), the head cycle is finished (CR-11 and CR-9), the load station is full (LS-51), the unload station is empty (LS-52), and the fixture is unclamped (CR-7). So

a combination of these contacts is used to latch CR-5, and to energize SV-1 and SV-3 after the bar is down, closing LS-2.

After the transfer bar has advanced to LS-4, energizing CR-4, the fixture must be clamped, indicating to the head that a new part is in place. And after clamping, the transfer bar must raise and return. To accomplish this, CR-4, Figure 6B, latches CR-11 as the signal to the head, and only if it does latch CR-11 is CR-12 released. If CR-11 failed to latch, the head wouldn't run. And if CR-12 were released (but without CR-11 latched) the cycles would continue as though there were no failure—except parts would be going through station 2 without being machined. This is the reason for the seemingly unnecessary CR-11 contact in series with the CR-12 release coil. CR-4 also releases CR-5.

The clamped condition of the fixture is indicated by LS-8 energizing CR-8. So that with CR-5 released and CR-8 energized, the solenoid valves SV-2 and SV-4 are energized to raise and return the transfer bar.

The head must cycle when a new part is in place and the fixture is clamped. Thus the cycle is on (CR-F), a new part is present (CR-11), and the fixture is clamped (CR-8). Solenoid valves SV-9 and SV-11 are energized to start the head forward. At the end of the stroke, LS-11 releases CR-11 to return the head to LS-9.

The fixture unclamps if the transfer bar is at its starting position (CR-3), and the head has completed a cycle (CR-9 and CR-11). This combination latches CR-12 to energize SV-6 and SV-8 to unclamp the fixture.

If during the machining cycle LS-51 and LS-52 are again closed, CR-5 would latch. Then when CR-7 is energized to indicate the fixture is unclamped, the transfer bar starts a new cycle.

#### 4. ADD MANUAL CONTROL

The fourth step is to add manual control to the existing automatic control while retaining the automatic safety interlocks. When tools are replaced or repairs made, it is necessary to operate parts of the machine out of sequence. Heads require jogging or inching control, and the fixtures must be operated if it is mechanically safe to do so.

When on manual control, CR-G is de-energized to prevent automatic operation and to make it possible to operate the machine with the manual buttons. The fixture can be unclamped or clamped with CR-12 if the head is up (CR-9) and the transfer bar is at one end of its stroke (CR-3 and CR-4).

The head can be run up and down with CR-13 and CR-10 if the fixture is clamped (CR-8).



# Solving Scientific Problems

**THE GIST:** Using various approximation techniques, most scientific problems can be solved by repetitively performing the common arithmetic operations. Some of these techniques have been known for ages, but their application was limited by the immensity of many problems in terms of time and manpower. Then came the electronic digital computer. It was ideal for the task, since it could add, subtract, multiply, divide, and compare at extremely high speeds.

Not only can the modern scientific calculator solve problems that couldn't be solved before, but it has led the way to problems that hadn't even been thought of before. These problems range from the solution of systems of linear equations to the simulation of real-life situations. By outlining the general characteristics of scientific calculators and the types of problems they can handle, it is possible to specify the requirements for a good computer. Next month's article will survey the available calculators to see how they satisfy these requirements.

JOHN W. CARR III, University of Michigan

Scientific calculators are the chief tools in the computation laboratories of university, government, and industrial research centers. Scientists, engineers, and mathematicians describe models of physical, empirical, or logical systems in language the machine can accept, insert numerical parameters, and obtain answers that may validate a theory on the basis of agreement with experimental results, provide the design parameters for all types of systems, or predict the behavior of devices as yet unbuilt.

The heart of a scientific calculating system is a large-scale, general-purpose, high-speed, stored-program, electronic digital computer, as first described by Burks, Goldstine, and von Neumann<sup>2</sup>. These computers rose out of the traditional sequential use of arithmetic, with internal decision making based on partial results. Of course, not all computers are selective-sequenced with a stored program. Other varieties of computing machine structures are inherited from different traditions. For example, the digital

differential analyzer was developed by applying pulse techniques to the structure of an analog computer operational amplifier. These unusual off-shoots, however, are outside the main stream of present-day digital computation, and will not be discussed here. In general, they gain somewhat in calculating speed by performing operations simultaneously: but they lose flexibility, number handling, and decision making ability.

Figure 1 shows a flow diagram of engineering design procedure, which might be considered a complete scientific calculating system from the beginning of a problem to a completed design<sup>3</sup>. In this system, all of the blocks within the dotted lines can be handled automatically by high-speed digital scientific calculators. Those blocks outside the dotted lines have not been successfully attacked by machine techniques. They require human intervention. Thus a scientific calculating system has an electronic digital calculator embedded in a larger data-processing system, with interplay between the automatic computer and the mathematician or engineer.

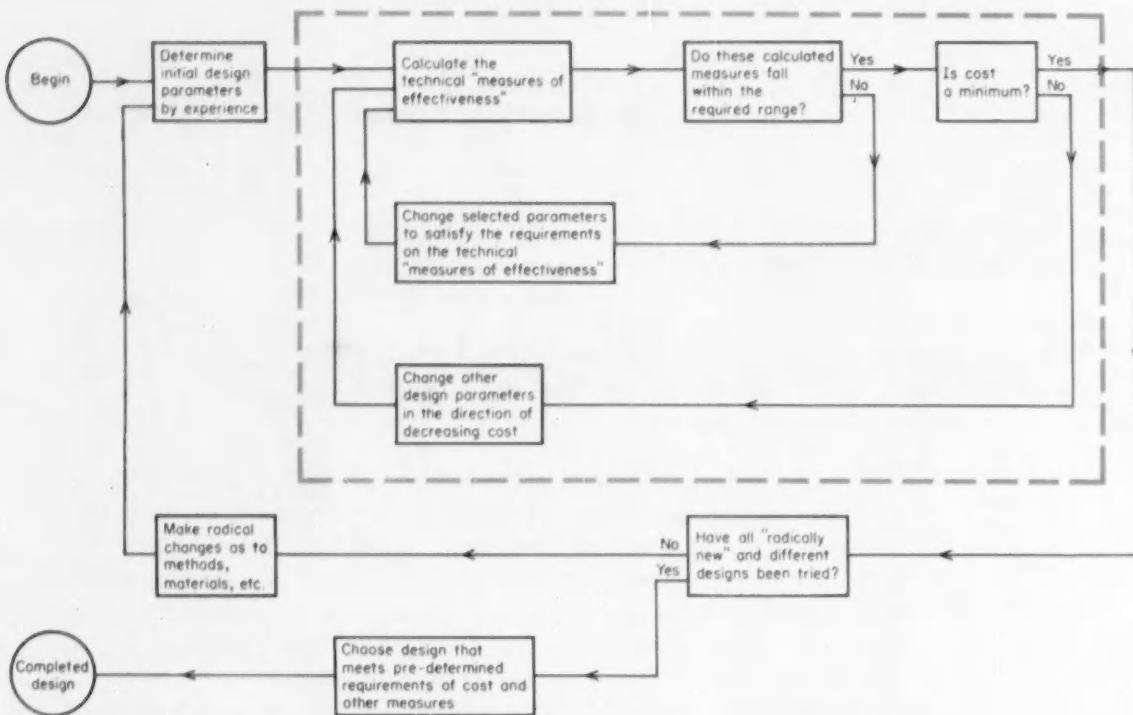


FIG. 1. Flow diagram of the design procedure in engineering. All operations enclosed by dotted lines can be handled automatically by high-speed digital scientific calculators. (From Bennett, "Faster than Thought")

## SCIENTIFIC VERSUS OTHER COMPUTERS

Most problems handled on a scientific calculator have never been solved before, at least in the size and scope achieved. And they are of a wide variety, ranging from the numerical solution of problems in aerodynamics and nuclear reactor structure, to the logic of switching circuits and computers themselves. Thus, most scientific calculators must be more nearly true "general-purpose" machines than business and "real-time" control data processors<sup>1</sup>. In many cases, the problems that are later transferred to one of the other types of data-processors are originally "simulated" on a scientific calculator.

Since scientific problems come from many sources, they tend to vary widely in size. Therefore, scientific calculators that are to compete with punched-card machines or desk calculators must handle short problems as efficiently as long ones.

The size and number of problems encountered in a computing laboratory differ greatly from those encountered in the "production" use of a data-processor on repetitive work. One large problem on a data-processor may actually consist of thousands of very small ones (individual payroll or aircraft position calculations), each handled within an overall framework. Scientific problems can have the same structure (for example, the solution of simultaneous equations under a multivariate combination of de-

sign parameters), but they also range upward to the solution of several-dimensional partial differential equations, where the result, after hundreds of millions of operations, depends on the very first operation in the sequence and all those in between. A scientific calculator located in a research laboratory or one servicing many varied sources of problems will probably be expected to solve problems ranging in size from a few thousand operations up to many millions. Some laboratories require a large-scale calculator to solve a hundred or more different and relatively small-size problems in a 24 hr period.

### Comparative Problem Structure

Many problems solved on scientific calculators make little use of other than the arithmetic operations. In a study of three "typical" problems performed on the Maniac at the Los Alamos Laboratory of the Atomic Energy Commission, Herbst, Metropolis, and Wells<sup>2</sup> noted that the output of a mechanized "code analyzer" indicated no drum transfers and no magnetic tape handling. At the same time, in a "hydrodynamics problem", almost 65 per cent of the total computing time was devoted to multiplication and division. Granting a bias to small problems, and noting that the Los Alamos group in question does not operate in exactly the same fashion as other installations, it is still possible to apply these conclusions to a variety of small problems.

Thus most scientific calculations have been marked by a relatively small ratio of data processing and data transfer to calculation. When larger problems involving more complicated geometries are attacked, and it is necessary to call on secondary storage devices more often, this ratio may increase. Nevertheless, most problems on scientific calculators appear to be "process limited"—limited by calculating speed; while the newer business problems as performed on available machines are generally "tape limited"—limited by access time to secondary storage.

The major difference between scientific, business, and real-time data processors is in the input of information. Even when it handles the most elaborate table-formulating problem, a scientific calculator operates with only a medium amount of input and output data. A real-time computer, in a semi-automatic environment, will have only "exceptional" information transfer with the operators; but a business-data processor, first and foremost at this stage of development, must present written outputs to large numbers of people. The payroll record for 25,000 people may require for one particular procedure an input of several million characters from externally prepared records, with a comparable amount of output data processed by human operators. In contrast, the numerical solution of initial value partial differential equations on a scientific calculator may require no other numerical input than a few thousand decimal digits, and may run for hours, delivering an output at widely separated intervals.

For efficient operation, a scientific calculator must be able to handle innumerable repetitive calculations; examples include solution of aircraft dynamics for numerous parameter combinations, tracing of many rays through a lens system, or successive iterations to determine the solution of a classical boundary value problem. Because it deals with long sequences of operations, a detailed error analysis is required. This can be either preliminary, or carried along

parallel with the actual computation. In any case, when the answer is obtained it is bracketed within values that express the spread built up by "round-off" and "truncation" error. No such error analysis is needed with real-time or business-data processors.

Another important point is the ease with which a problem can be expressed in machine language. Because of the variety of problems and the short operating time per problem, "programming" or "coding" a scientific calculator is generally more difficult than programming a business-data or real-time computer. However, mathematical notation is simpler and more nearly logical than the language of business, whose lack of as exact an external language tends to handicap the person using a data-processor on business problems. In general, the mathematician or engineer presenting a given sized problem to a scientific processor has an easier overall formulation and coding task than the business procedures specialist in the throes of translating a problem of the same size into concise machine language.

Most of the larger business-data processing problems require only one original problem formulation, which is carried over to a daily, weekly, or monthly performance for a long period of time. Scientific calculating laboratories, with scores of problems each day, require a much larger ratio of formulation and programming time to machine running time, even though the basic data-processing problem may require ten or more man-years before it can be set to run over a several-year period.

Based on available experience, an efficient and reasonably priced scientific calculator might boast of high speed, easy interchangeability of problems, flexibility, reasonable (but not vast) secondary storage, adequate (but not ultra-speedy) input-output, aids in error analysis and easy programming, Table I. As is pointed out in the next article, none of the commercially available equipments fills all requirements, but many offer a satisfactory compromise.

TABLE I—CHARACTERISTICS OF A SCIENTIFIC CALCULATOR

|   |   |
|---|---|
| Structure of Computer   | Nonspecialized general purpose calculator.  |
| Arithmetic and Storage number systems                         | Binary or binary-coded decimal depending on need for large quantities of "logical" calculations; should have ability to handle alphabetical characters. |
| Arithmetic mode of operation                                  | Preferably floating point for ease of set-up of different problems.   |
| Size and number of problems                                   | Many large and small problems of varied structure and type.   |
| Amount of internal data processing and data transfer involved | Ratio of internal data processing and data transfer to calculation is relatively small.   |
| Amount of input-output to and from human beings               | Medium amount of data to and from human beings.   |
| Need for easy methods of formulation and programming          | Important because of large number of problems being solved.   |

## THESE PROBLEMS CAN BE SOLVED

Most of the problems solved on scientific calculators have been in the fields of the physical sciences and engineering design. But the recent application of classical and newer mathematical techniques to the problems of business management has shown that these problems are also open to solution on the same machines.

Many problems in the physical sciences and engineering are linear, since the variables, and in some cases the functional derivatives, in the mathematical formulation occur in the simplest form, raised only to the first power. Other problems have mathematical formulations that can be "linearized" by neglecting certain nonlinear effects. In either case, the scientific calculator can solve large systems of linear equations (up to several hundred) to the required precision in a reasonable period of time. For example, complex problems in network analysis can be handled with standard "routines" already prepared for many calculators. Functional approximation techniques, such as polynomial, rational function, or continued fractions, can be applied to actual network synthesis, using the linear systems procedures to design a network with approximately the desired frequency- or time-domain response.

An important property of linear networks, whether electrical or mechanical, is the characteristic frequency of vibration. This frequency can be determined by using standard computer routines, developed for obtaining the characteristic values of matrices of orders up to several hundred. In servomechanism theory, the real and complex parts of the roots obtained by this procedure indicate system stability. While the extra instability introduced by the computer elements themselves sometimes makes it impossible to solve stability problems on an analog computer, digital scientific calculators are generally capable of developing a solution. Similar calculating techniques are used in such related problems as the binding energies of atoms in molecules, and the period of rotation of planets around the sun.

## Nonlinear Problems

Although mathematical theory has not yet probed all possible nonlinear problems and the techniques for solving them, large-scale digital computers can handle nonlinear extensions of many linear problems. This means that physical and engineering problems, the majority of which are nonlinear, no longer need be linearized, and that for the first time problems can be attacked and solved in their original form, without a series of restrictive approximations.

For example, many former linearized solutions of ordinary differential equations are now being repeated in full nonlinear form. By selecting the proper "finite difference" approximations to derivatives, and using a small enough step size, results can be obtained that are as close as desired to the true solution of an equation. In fact, a general-purpose digital scientific calculator can be disguised as an electronic differential analyzer, so that problems set up for the latter can be just as easily solved on the former<sup>7</sup>. At the present time it is difficult to tie digital computers in with actual operating systems (compared with the relative ease of tying in an analog computer). However, this difficulty may be overcome if current experiments in directly connecting an ERA-1103, Figure 2, with actual equipment or with analog computers are successful.

Many large systems of ordinary differential equations have been solved in evaluating the response of aircraft and guided missiles. The technique has also been applied to such problems as economic cycle prediction theory and reactor transients.

## Partial Differential Equations

In theory, at least, many of the ordinary differential equation systems can be solved with analog computers, punched-card equipment, or desk calculators, if enough time and manpower is available. However, this is not true with partial differential equations. With a few simple exceptions, these equations could not be solved without electronic calculators. Here again, derivatives are replaced by "finite dif-

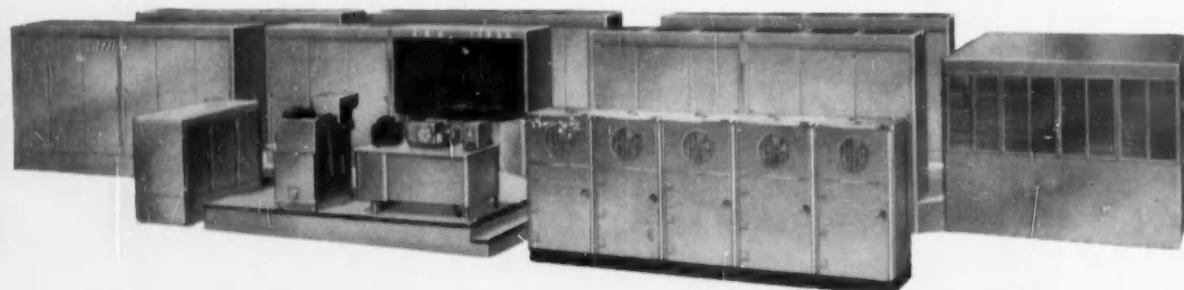


FIG. 2. Built primarily for scientific calculations, the ERA-1103 (UNIVAC Scientific), has special features for interconnecting the computer with external electronic equipment. When its chief competitor, the IBM Type 704, comes off the

production line, there will be two commercially available real-time calculators that can double in handling such high-speed problems as missile systems control and simulation interconnections with analog computing equipment.

ferences" so that high-speed arithmetic operations can be performed on the discrete variables.

Partial differential equations are encountered in the theory and design of nuclear reactors, electromagnetic theory, problems in vibration and sound, quantum mechanics, fluid dynamics (such as the latest formulations of the weather prediction problem), and elasticity. The mathematical theory behind the numerical solution of nonlinear problems has not been studied as thoroughly for partial differential equations as it has for ordinary differential equations. Thus the solution of many problems requires further study, as well as direct calculation.

### Simulation and Monte Carlo Techniques

In many cases it is possible to directly "simulate" a physical situation, thus not formulating the problem in a completely classical manner. An entire class of problems can be attacked by the "Monte Carlo" process, conceived by physicists at the Los Alamos Scientific Laboratory for solving complicated reactor shielding problems. The computer plays a "probability game", predicting the behavior of neutrons that are scattered from or absorbed by successive nuclei in the shielding material by following the "track" of the particles. Although generally more complicated statistical procedures must be considered, this technique of "model building", combined with the generation of "pseudo-random" behavior inside the computer, can directly simulate problems that otherwise could not be solved in a reasonable length of time.

On MIDAC at the University of Michigan, computer simulation was used to describe traffic behavior at a crowded intersection<sup>8</sup>. The success of this first experiment, which satisfactorily demonstrated the traffic variation with change in traffic-light timing, turn probabilities, and input of cars to the intersection, indicates that a similar simulation can be performed for a multi-intersection traffic grid. A multi-intersection grid cannot be described easily by classical techniques, so that direct simulation is probably the simplest method of solution.

In many cases, problem solutions can be expressed directly as "closed form solutions" that describe an answer in terms of the elementary functions, their powers, and integrals. While many such formula evaluations must be handled by high-speed scientific calculators, it often turns out that the original problem can be solved as easily by one of the newly rediscovered numerical-analysis techniques as by the evaluation of the classical closed form.

Numerous problems in "data reduction" should be included among these formula evaluations. Large quantities of numbers from a jet test stand, guided missile telemetering system, or some other large-scale experiment, must be inserted into a relatively simple formula to obtain key numerical measures of the experimental performance of the system under study. These problems require computer per-

formance somewhere between that of a scientific calculator, where there is no absolute time deadline, and a real-time processor, where deadlines are continually arising.

### Managerial and Social Science Problems

Modern scientific calculators have increased emphasis on the application of both classical and newer mathematical techniques to the field of management. Techniques range from the use of simple statistics up through highly complicated linear programming<sup>9</sup>. The latter involves the extension and application of the classical theory of linear inequalities to such diverse problems as the location of centralized warehouses and the assignment of air-crew personnel for highest overall fighting efficiency.

Since the linear programming problem involves maximizing or minimizing some "measure of effectiveness" (such as profit, or time and cost), the techniques cover a multitude of real-life situations (provided that the original formulation can be linearized). Many more nonlinear problems must await further mathematical theory before they can be easily solved on calculators. Other attempts, such as trials to determine the best combinations of stocks for an investment portfolio, must await better input information before satisfactory answers can be obtained.

Management also gains from the solution of the combinatorial problem. Here the machine is instructed to determine an optimum procedure by trying all possible combinations, or sampling desirable combinations, of a particular configuration. An example is an assembly line scheduling problem, where certain assembly operations must await the completion of preceding ones while others can all be performed at the same time. With complete knowledge of the priority relationships, and a high-speed automatic calculator to juggle the sequences within the limiting restrictions, large performance improvements have been obtained in several cases.

## WHAT TO LOOK FOR IN A SCIENTIFIC CALCULATOR

Many industrial, commercial, and educational organizations are faced with the problem of deciding what size, kind, and make of scientific calculator or data processor they should obtain. Several thorough surveys of all possible equipments have been based on manufacturers' statements<sup>10</sup>. Of course, all manufacturers are willing to give a complete description of their equipments, based on their opinion of their performance. The next article in this series will attempt to add to manufacturers' statements some objective comments on available equipments.

At a Special Conference on Digital Computers and Data Processors at the University of Michigan last August, 17 users of equipment gave "Reports from the Users", which were taken down verbatim with questions and answers<sup>11</sup>. Where they apply, excerpts from these reports will be quoted.

Besides hearing the arguments of the various computer manufacturers, it pays for every incipient user to consult experienced and objective personnel, either inside or outside his own organization. A survey of the present users of equipment under consideration, including visits to installations, is imperative.

The first decision to make concerns the principal types of problems to be handled by the new equipment. Even this doesn't necessarily decide the pattern of equipment, since many business-data processors are also used for engineering calculations. At least one large installation plans to use a scientific calculator for both scientific and business problems, under the theory that a fast scientific calculator with suitable input-output equipment can perform better than any of the present business-data processors. (See the "Report" by H. R. J. Grosch of General Electric's Gas Turbine Div. on the proposed use of an IBM Type 704 calculator with Type 705 business-data processor peripheral equipment<sup>11</sup>.)

The question of whether to rent or buy must be weighed in the light of both the financial and technical capabilities of the organization getting the calculator. Buying rather than renting is usually cheaper, but does not provide as much protection from technological obsolescence. Also, buying generally means the purchaser must furnish his own maintenance personnel. If a computer is to be altered for experiments with real-time applications, it usually must be purchased.

An operating electronics firm might tend to buy, an insurance company to rent; a university with an electrical engineering department capable of altering a computer might buy, and a nonengineering college might rent.

### Programming Techniques

Original problem set-up procedures for computers required an instruction-by-instruction human hand translation of the problem into machine language. But with the advent of "automatic coding" techniques, in which individual external instructions correspond to groups of internal instructions, the computers themselves perform much of the clerical portion of programming and coding and at the same time avoid many human errors. The new user of a scientific calculator should make sure that the computing equipment under consideration can be adapted to automatic coding, or else be willing to spend many man-months on programming. Libraries of subroutines, automatic assembly programs, compilers, generators, translators, interpreters, and all the other techniques developed over the last five years have shown that much of the difficult and time-consuming job of coding can be eliminated.

Input and output are often the weakest links in present-day equipment. On the average, 30 of the 40 monthly failures on the University of Illinois' Illiac are due to input-output. (See "Report" by Professor James Robertson of Illinois<sup>11</sup>.) The aver-

age new computer user normally feels that a low-speed input or output device will not bottleneck his operation. But once the machine is being used regularly, external information handling delays soon prove intolerable. Regardless of machine cost, any stored-program scientific calculator should have an input speed of at least 200 decimal or alphanumeric characters, and an output speed of at least 50 characters. If the equipment is to be used in conjunction with available punched-card equipment, punched-card input-output is important. Otherwise, paper tape or magnetic tape input should be satisfactory.

### Internal Computer Characteristics

Internal computer characteristics are important insofar as they affect the usability ease of a calculator and its electronic reliability. In present-day calculators, reliability varies inversely with the number of tubes, because of the inherent relative unreliability of vacuum tubes. Big advances in reliability are expected from the next sequence of computers, now on the drawing board, since they will have none, or only a few, vacuum tubes. However, preventing tube failure during operation is just as important. "Marginal checking" is one of the most common and workable preventive techniques. Computer voltages are varied during maintenance periods to determine which tubes or other components are apt to fail.

Although John von Neumann (considered the original designer of the present-day class of calculators) originally recommended the binary number system<sup>2</sup>, it is worthy to note that he later participated in the Navy's design specifications for the NORC (Naval Ordnance Research Computer), built by IBM and now located at the Naval Proving Grounds, Dahlgren, Va. The NORC has a binary-coded decimal number system for easy external number handling. Similarly, although the original Princeton general-purpose design<sup>2</sup> recommended a fixed-point method of computation, with numbers in absolute values less than one, the NORC uses full floating-point arithmetic (fractional number plus decimal exponent). Both the binary-coded decimal number system and full floating-point arithmetic are extremely useful in scientific calculations, and a computer including both features should rate high. Built-in floating point saves time in problem formulation, since complicated prescaling of a problem where the partial results are obviously unknown is unnecessary.

### Computer Storage

Particularly important in storage capacity is the relationship between the higher-speed, fast-access primary storage and the slower-speed, slow-access, but larger secondary storage. The earliest designs had at least 1,000 "words" or locations of primary-access high-speed storage, each containing the equivalent of perhaps 12 decimal digits. In a stored-program scientific calculator, 1,000 words is the absolute

minimum acceptable amount of direct-access primary storage.

The high-speed magnetic cores or electrostatic tubes that some computers use for primary storage have access times in the order of 10-50 microseconds per piece of information. The cheaper machines often use the less expensive magnetic drum as a primary storage device. Since access to a particular piece of information on the drum must wait an average of a half-revolution (5 to 20 msec, depending on drum speed), the latter machines may be from 100 to 1,000 times slower. The user of a slower-speed magnetic-drum machine should insist on more primary storage, since it is often possible to trade storage locations for time by tricky programming. For this reason, a magnetic-drum calculator should have at least 2,000 locations of drum storage, of at least ten decimal digits each.

The amount of direct-access primary storage often turns out to be insufficient to handle many quite ordinary problems, particularly if the machine uses binary arithmetic and needs complicated input-output conversion techniques. Then the user is forced to turn to secondary-storage devices, such as magnetic tape or the less useful punched cards or punched paper tape. Where machines have fast primary storage, drums can also be used as secondary storage.

Magnetic tape is useful in the many formula evaluation and data reduction problems that require large quantities of information to be handled. A prospective user should carefully weigh the relative speeds of the central processor, including primary storage, and the tape units. It is possible that the speeds are mismatched, and that the benefits are out of line with the cost of additional tape units. In some cases, the magnetic tape equipment, designed several years after the original computer, is much too fast, compared to the magnetic-drum primary storage, to be used as efficiently as its cost demands.

#### Instruction Codes

In the early days, a violent controversy raged between proponents of machine instruction codes using "one-address" and "three-address" logic. In one-address logic, an accumulator with a known address is the location of one of the operands or the result of an instruction, while in three-address logic, three addresses in each instruction locate the two operands and one result. One-address instruction logic is more flexible, but the three-address logic is easier to learn. With the advent of automatic programming, which may vary back and forth between one-, two-, three-, (or even more) address logic, the actual structure of a computer became less important. And the number of addresses in an instruction word is less important than the availability or nonavailability of coding techniques that permit the computer to perform much of the clerical labor required to prepare instructions.

In some scientific calculators, the digit length of

the basic machine "word" can be varied by a factor of two. This feature is useful if primary storage is limited, but with adequate primary storage it will probably never be used. Some business-data processors, such as the BIZMAC and IBM Types 702 and 705, have a completely variable word length so that a number can be stored with an arbitrarily-sized sequence of digits. This would be extremely useful in experimentally determining round-off errors. However, the variable word-length procedure, requiring slower serial arithmetic, results in slower operation. This means that for scientific problems, the slower data-processors are noncompetitive with similarly priced machines designed as scientific calculators.

#### Optimum Cost and Size

Bigness, when equated with high speed and large storage, has a direct relationship to efficiency. Most experienced users agree that the larger and more expensive the machine, the lower the unit cost per operation.<sup>12</sup> This implies that one magnetic-core-storage calculator costing \$1 million can do much more than four times the work of four smaller magnetic-drum calculators costing \$250,000 each. (Of course, if four different geographical locations are involved, this might not apply.)

It is interesting to note that the NORC is about ten times faster on many problems than any other existing computer. Similarly, the design for the LARC (Livermore Automatic Research Computer), to be built by the Eckert-Mauchly Div. of the Sperry-Rand Corp., calls for over 25,000 words of high-speed magnetic-core primary storage, with decimal floating-point arithmetic. Obviously, such machines can be built at this stage of computer development. And



FIG. 3. The IBM Type 650 Magnetic Drum Calculator next year is to add alphanumeric data handling, magnetic-tape storage, floating-point arithmetic and a small quantity of magnetic-core storage (at increased rental) to its present numerical data handling, magnetic drum storage, and fixed-point arithmetic abilities. Although designed as a scientific calculator, it may be used more often as a business-data processor, mainly because there is no true data processor available in its rental range.

although the user may not be presently confronted with problems of the size of those to be solved on the LARC, he still should be prepared to see his present machine pressed to capacity as the skill of the operators and increased experience of the problem-positers result in more complex problems.

### Reliability

In any type of computer, equipment reliability means the difference between smooth operation and a continuing struggle between user and equipment. Because of careful original design, even equipment developed several years ago has proven very reliable. For example, users of the Reservisor, a reservation accounting system at American Airlines, LaGuardia Field, New York, claim an average "down-time" of only 0.2 per cent out of each 22-hour operating day. This excellence was accomplished by building two identical computer and storage units, with a basic packaged construction. (Note that this low percentage does not include failures in input-output.

Similarly, the results of the acceptance tests for the ERA-1103 (UNIVAC Scientific), as reported by Richard Castanias of the Vitro Corp<sup>11</sup>, show that the Eglin Air Force Base computer operated more than 43 hours with no errors, the only stoppages being due to paper-tape punch clogging. R. W. Bemer of Lockheed's Missile Div. noted that an IBM Type 650, Figure 3, operated consistently, unattended and without error, over weekends; and Professor A. J. Perlis of Purdue stated that the

University's Elector Data Datatron had performed for one month with no errors in the central computer, and with only a few in the input-output equipment<sup>11</sup>. In all these cases, and in the other "Reports," input-output was consistently the chief source of failure. Those computers with internal checking devices performed even better. One user of both an IBM Type 701 and a UNIVAC reported that the latter computer, while much slower, was almost as cheap per unit operation. The UNIVAC's built-in checking prevented machine error propagation, while the 701 missed errors in the electrostatic memory because of the absence of built-in checks.

The latter difficulty can often be overcome by using programmed checks. A better way to reduce such errors is to use magnetic-core storage, as is being done on the Type 701's successor, the Type 704, and on the ERA-1103A and other machines. W. H. Papian of MIT, designer of the Whirlwind I core-storage system, the prototype for most that have followed, noted that there appeared to be a two-months' mean-free-path between errors on the Whirlwind core storage, and that failure came in the associated tubes rather than in the cores.<sup>11</sup>

All this indicates that purchasers or renters of scientific calculators should insist on extreme reliability from the central control, arithmetic, and primary storage units of their new systems, but at the same time should study carefully the performance of proposed input-output and secondary storage systems, still the main causes of machine unreliability.

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DR. JOHN W. CARR

John W. Carr got started on digital computers as an assistant on Project Whirlwind at MIT in 1948. In '49, a new MS in EE, he went to the Sorbonne on a Fulbright. While in Europe he put two months into learning the character of Cambridge U.'s new EDSAC, then returned to Whirlwind to set up its Subroutines Library. Carr's PhD thesis in 1951 dealt with solving partial differential equations with high-speed computers. In '52 he joined U. of Michigan's Willow Run Lab to ready MIDAC for use, later supervised the computer facility. Last year he became Assistant Professor of Mathematics at the University; he still consults at the Lab and runs computing courses for industry.

# Two-Capacitor Method of Phase Shifting

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In ac servomechanisms, it is frequently necessary to shift the phase of the voltage on the motor main field winding with respect to the line. There is no simple means of maintaining this exact phase shift at all speeds. However, the two-capacitor method shown in the accompanying sketch gives excellent results for small instrument servomotors when adjusted with the motor stalled. In contrast with the more usual single-capacitor method, using two capacitors permits simultaneous adjustment of both voltage magnitude and phase on the main winding.

Table I lists a complete set of equations for establishing capacitor values. Once capacitance is determined, capacitor voltage can be calculated from the equations in Table II. The following two examples will clarify the use of this technique.

## Example 1

The Bureau of Ordnance MK-7, 400 cycle, 115 v servomotor has a rated current of 0.110 amp at stall and a power factor of 0.5. Determine  $C_1$  and  $C_2$  and their voltage ratings if a 90 deg phase shift and unity magnitude ratio are to be achieved from a 115 v line.

Referring to Table I, use Equations 7 for 400 cps:

$$C_1 = 397.8 \frac{(0.5)(0.110)}{115} = 0.190 \text{ mfd}$$

$$C_2 = 397.8 (0.110) \frac{(\sqrt{1 - 0.5^2} - 0.5)}{115} = 0.139 \text{ mfd}$$

and the Equations of Table II to determine the voltage across the capacitors:

$$V_{C1} = 115 (1 + 1)^{1/2} = 162 \text{ v}, V_{C2} = 115 \text{ v}$$

## Example 2

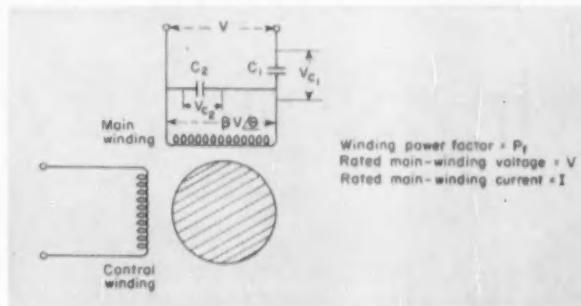
For a variation in the way these equations can be used, assume that a 90 deg phase shift is to be obtained with the motor discussed in Example 1 without using  $C_2$  (in other words,  $C_2$  equals 0). Determine the voltage impressed on the main motor winding under this condition.

Setting Equation 4 in Table I equal to zero,

$$0 = \sqrt{1 - Pf^2} - BPf$$

Then  $B$  can be expressed by  $B = \frac{\sqrt{1 - Pf^2}}{Pf}$

and where  $Pf$  equals 0.5, the motor must be designed to accept 200 v on its main winding.



Schematic of two-phase servomotor. Line voltage is shifted by angle  $\theta$  and attenuated by  $B$  to rated motor voltage.

Table I—Capacitor Values for Various Phase Shifts and Magnitude Ratios

General Form—Any phase shift and any magnitude ratio.

$$(1) \quad C_1 = \frac{B Pf I}{\omega V} \csc \theta$$

$$(2) \quad C_2 = I \left[ \frac{(\cos \theta - B) Pf + \sin \theta \sqrt{1 - Pf^2}}{\omega V \sin \theta} \right]$$

Special Form—For 90 deg phase shift and any magnitude ratio.

$$(3) \quad C_1 = \frac{B Pf I}{\omega V} \quad (4) \quad C_2 = I \left[ \frac{\sqrt{1 - Pf^2} - B Pf}{\omega V} \right]$$

Special Form—For 90 deg phase shift and unity voltage ratio.

$$(5) \quad C_1 = \frac{Pf I}{\omega V} \quad (6) \quad C_2 = I \left[ \frac{\sqrt{1 - Pf^2} - Pf}{\omega V} \right]$$

Special Form—Equations 5 and 6 for 60 and 400 cycles.

| (7)         | 60 cps  |                        | 400 cps   |                        |
|-------------|---|------------------------|---|------------------------|
|             | $C_1$ , mfd   | $2,652 \frac{Pf I}{V}$ | $C_1$ , mfd   | $397.8 \frac{Pf I}{V}$ |
| $C_2$ , mfd | $2,652 I \left[ \frac{\sqrt{1 - Pf^2} - Pf}{V} \right]$ |                        | $397.8 I \left[ \frac{\sqrt{1 - Pf^2} - Pf}{V} \right]$ |                        |

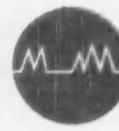
Table II—Capacitor Voltage Ratings

Across condenser  $C_1$

$$V_{C1} = V (1 + B^2 - 2B \cos \theta)^{1/2}$$

Across condenser  $C_2$

$$V_{C2} = BV$$



# Communication Theory In Digital Systems

**THE GIST:** Communication theory has been derived from the composite work of mathematicians, statisticians, physicists, and electrical engineers. Its application immeasurably aids the efficient design and use of digital computers. For instance, considering the information content shows how messages can be reduced in length for minimum storage capacity and yet retain their full significance. A practical example, taken from quality control tests, is discussed in this article. It indicates several coding methods that save storage space.

Another example: as the digital data proceed from the input, through the computer, to the output device, these data suffer corruption of content through round-off and truncation errors. The extent and effects of these corrective influences are also covered here.

The authors also consider programming, checking, transmission capacity, transmission rate, and the relationship of the major functions of a computer to the overall production of information useful to the operator but not available from the input data.

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Communication within a digital computer system is a three-path process. As shown in Figure 1:

- the operator communicates his problem to the computer
- extensive communication occurs within the computer during the course of the problem
- the computer communicates its results back to the operator or to some special system; for instance, a controlled machine.

Within the computer, as in most communication channels, the communicated messages consist of ordered sets of discrete symbols that represent the physical states of the computer's mechanism.

## INFORMATION THEORY

For instance, consider a single symbol chosen from an available set of symbols—say a letter of the alphabet—where the choice of any one of the symbols in the set is assumed equally probable. If  $n$  is the number of symbols available, then this symbol can be chosen in any one of  $n$  ways. If the message contains more than one symbol, selection of the second symbol occurs in the same way. Thus,  $n$ ,  $n^2$ ,  $n^3$ , etc. represent the number of different possible messages containing one, two, three, etc., symbols.

The measure of the informational content of a message depends on the logarithm of the possible number of messages. It is reasonable to assume that a message's information content increases with the number of its symbols. For a message  $L$  symbols in length, the quantitative measure of the amount of information,  $H$ , equals  $\log n^L$  or

$$H = L \log n.$$

Thus each symbol in the message conveys to a recipient an amount of information equal to  $\log n$ .

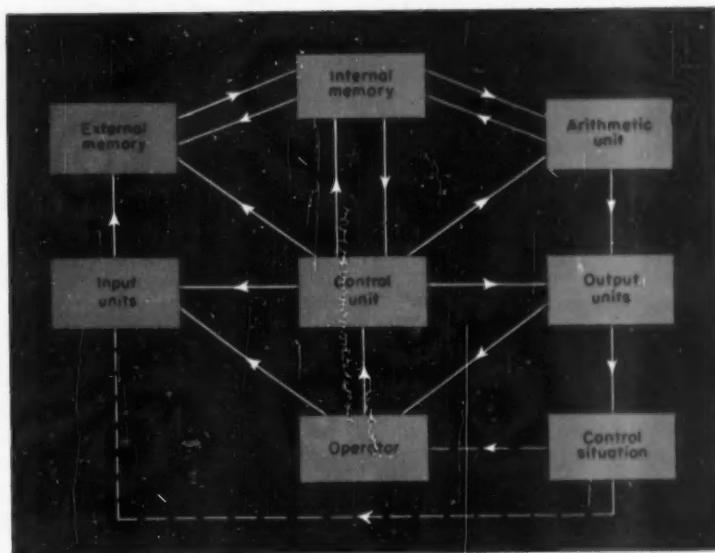


FIG. 1. This block diagram illustrates the three major paths of communication within a computer system. The first is from the operator to the input units, the second within the computer itself, and the third from the computer back to the operator or to a special control situation.

Of course, for this message to comprise significant information, the recipient must be able to decode the message and take seriously what it says, but not be able to predict it in advance. If the logarithms are taken to the base 2, then the measure of the information is in binary units, or *bits*. This simplest choice, between two equally likely symbols, gives

$$H = \log_2 2 = 1 \text{ bit}$$

as the amount of information conveyed per symbol.

#### Non-uniform Probability

Generally, not all symbols are equally probable. For example, in the English language not all letters occur with equal frequency. In fact, if a message is long enough, one predicts not only the letter frequencies, but the frequency with which one letter follows another. For example, *h* frequently follows *t*, and *u* always follows *q*. The effect of this prediction is to reduce the information content, because part of the message tells the recipient something he already knows. The previous definition of information content now requires modification.

For messages of  $n$  symbols, where  $P_i$  is the probability of the  $i$ th symbol, the information content,  $H$ , per symbol becomes<sup>1</sup>

$$H = - \sum_{i=1}^n P_i \log_2 P_i.$$

$H$  is maximum when all  $P_i$  are equal, and under this condition its maximum value equals  $\log n$ .

#### Information Storage

The problem of storage consists of reducing the

message to the shortest length that still permits highly probable reconstruction to its original informational content. Then less storage capacity will be required than for the original message. Note the fundamental distinctions between the informational content of a message and the capacity required to store this message; and also between the information-generation rate of a message source and the capacity (as a rate) of a communication channel required to transmit information.

A message in the English language does not require a full 26-state capacity to store each letter of the message. Portions that are redundant or devoted to known characteristics of the probability structure may be left out. The most efficiently transmitted or stored message is one whose every part is independent and uniformly random.

#### Coding for Minimum Capacity

The efficient coding of non-random messages equalizes the probabilities of all possible coded messages, permits higher informational content, and reduces the storage capacity required. We may consider a problem of coding messages with unequal probabilities. The information comes from a quality control test and the results go into a binary storage bank:

| QUALITY | PROBABILITY |
|---------|-------------|
| A       | 0.80        |
| B       | 0.15        |
| C       | 0.04        |
| D       | 0.01        |

For example, a sequence of 28 tests results in the following typical distribution, grouped in blocks of four for convenience:

AAAB AAAA ACAA AAAA BAAA AAAA BAAD  
(28 symbols)

If the following straight binary code is attached to each symbol, (A—11; B—10; C—01; and D—00) 56 storage bits are needed to store the 28 symbols, or 2.0 storage bits per test.

Straight binary sequence:

11111110 11111111 11011111 11111111  
10111111 11111111 10111100 (56 bits)

But another code can be used that examines sequences of up to four symbols until the first non-A symbol (if any) is encountered. Here, the position and letter of the non-A symbol follows these codes:

| POSITION | CODE | LETTER | CODE |
|----------|------|--------|------|
| 1        | 100  | B      | 0    |
| 2        | 110  | C      | 00   |
| 3        | 111  | D      | 000  |
| 4        | 101  |        |      |

The blocks are scanned until the non-A symbol occurs and its position and letter are noted by the code. If all four of the symbols are A's, then only code 101 is used. Note that each of these position-identification groups starts with a 1. Here is how the test sequence looks with this second code:

10101011100010111101011010111000

Thus, in reading the coded message, the first three binary digits give the location of a non-A symbol, and the following 0's identify the letter. Then the next group of three digits starting with a 1 gives the next position information.

The short sequence above requires  $32/28 = 1.15$  bits per symbol. This appears fairly efficient in view of the low-probability D in the sequence. Another alternate code, with an average of 1.26 bits per symbol, derives from this simple code:

A—1; B—01; C—001; and D—0001

Here, the 1 denotes the end of a symbol code and so the sequence can be deciphered. Note that the symbol with the highest probability has been assigned the least number of digits. This procedure reduces the number of bits per symbol.

A practical example of the technique of using only

a small amount of storage is illustrated by the case of storing a particular mathematical function. It is not necessary to store a complete table of values for the function; only the coefficients of the power series representation need be stored.

### Transmission Capacity

The central problem in communication is to transmit messages efficiently through a noisy channel. Figure 2 shows the path of a signal from the source to its destination and the introduction of noise within the transmission channel. Noise, or random-signal generation, occurs in transmission and storage as a result of random thermal currents and unexpected combinations of circumstances, the statistical failure behavior of large groups of components, decay of storage elements, and other natural departures from ideal behavior.

The basic parameters that determine channel capacity for the transmission of information are the bandwidth and the signal and noise powers<sup>1</sup>:

$$C = B \log_2 \frac{S + N}{N} .$$

Here, B is the channel bandwidth in cycles per sec, S and N are the signal and noise powers, and C is the capacity in bits per sec.

## COMMUNICATION— FROM OPERATOR TO COMPUTER

The operator communicates his problem to the computer through a keyboard, which records the problem on punched cards or paper tape, or on magnetic tape. As a portion of the computer's external memory, this record constitutes a source of numbers and instructions for these numbers.

### Instructions

The computer can interpret and execute only simple operations. Therefore, a difficult part of the communication process involves the simplification of instructions into a form that the computer can

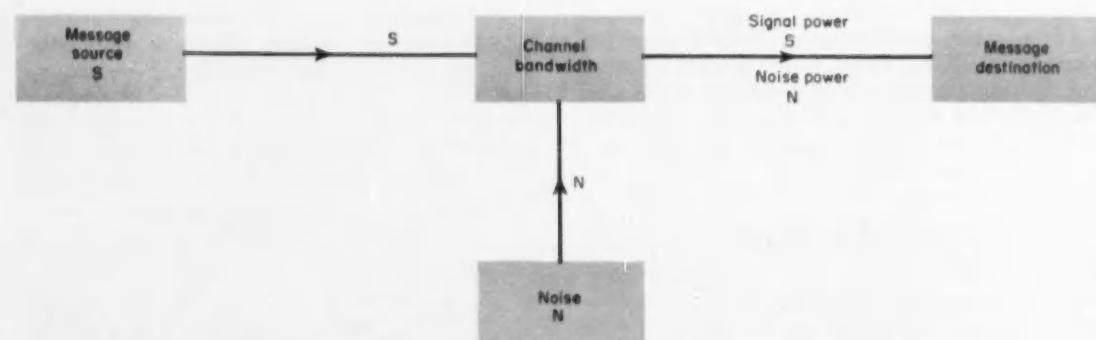


FIG. 2. As the digital message proceeds through the channel on its way to the destination it becomes corrupted by various sources of

noise, as shown in the block diagram above. Typical sources of noise are: power-line transients, thermal noise, and faulty components.

understand. For instance, the computer understands such simple commands as:

- add the number stored in memory location 010 to the number stored in memory location 011, place the sum in memory location 012, and then perform as an instruction the quantity stored in memory location 030; or
- if the number stored in location 012 exceeds the number stored in 013, perform as an instruction the quantity stored in 031; otherwise go to 032.

In terms of striking keys, these instructions may be represented by:

1010011012030  
5012013031032

where the initial 1 means add and 5 means compare.

### Programming

Most computers that have been operating for some time acquire libraries of instruction tapes and card decks that carry programs for a wide variety of computations. All the computer needs are the appropriate tape from the library and another tape that specifies the numbers for the problem. Or it may combine several library tapes with the aid of a super-program tape.

Interpretive programming may be used to simplify communication between the operator and the computer. The library program tells the computer not to obey its own instructions literally, but to interpret them as relatively short stored sub-programs for a variety of operations. Although the effective ability of the computer is expanded, it is at the expense of slowing down the computation because of the time required for interpreting.

In the program-checking interpretive mode, the computer keeps track of many things that might otherwise get lost in the normal execution of the problem. Among these items are:

- the identity of all memory locations whose contents have been changed during the computation
- printout of all individual arithmetic results, together with instructions executed in the sequence
- finding errors in programs, where the programmer did not command the machine to do what he thought he was commanding it to do.

When a computer operates in the interpretive mode, it can be made to accept almost any language, including algebra. Thus, computers that have the proper programs solve sets of algebraic equations when given the equations in literal form. Or the computer can be made to evaluate a definite integral from the mathematical form of the integral even when it contains transcendental functions.

The informational capacity of the input channel determines the speed at which data can be supplied to the computer. Ideally, the input rate should be so fast that the computer does not waste time waiting for data. Unfortunately, this aim is often not realized because many types of input devices are relatively slow.

### COMMUNICATION— FROM COMPUTER TO OPERATOR

The control panel communicates a small amount of information to the operator through its neon indicators. These lights show (in binary code) the contents of the arithmetic and instruction registers and program counter, and indicate the type of operation being executed. Although these lights flash much too fast to be read during the course of the computation, they freeze into a complex pattern when something goes wrong and the machine stops. This pattern can be read for the clue to the source or location of trouble.

The computers rapidly deliver information to a typewriter connected directly to the output of the computer; but this typewriter is still relatively slow. Directly-connected high-speed printers or output tape accept large quantities of information at the fastest rates. The information, if taped, subsequently operates a printer at some slower rate.

### COMMUNICATION— WITHIN THE COMPUTER

The computer acts as a communication channel from the input device, on which the problem is fed into the machine, to the output device, on which the machine delivers its results. The details of the communication process depend on the nature of the computer's circuitry.

Fundamentally, all existing electronic digital computers operate on binary signals. All communication, both internal and external, is couched in binary terms. Thus, the input keyboard codes the input characters in binary terms and the output printing device decodes them and prints the appropriate characters in the decimal system.

The binary character of the codes minimizes the chance that noise can cause an error and, ordinarily, errors where one state is confused with another arises from transients rather than noise. Less frequent are errors due to faulty components.

#### Signal-to-Noise Ratio

The large signal-to-noise ratio that exists in computer circuitry indicates a high information-rate capacity. This capacity could be increased and a higher speed of computation obtained by increasing bandwidth or using a many-state representation instead of the present binary technique. Here:

- shorter or steeper pulses and higher clock signal rates increase the bandwidth, but
- multi-state operation of tubes and storage devices is not reliable with presently available components.

Simplicity and the relatively low efficiency of the high signal-to-noise ratio of a two-state system form a compromise with the conflicting demands of equipment cost and reliability. Redundancy procedures and equipment in the computer combat random equipment and component failures, where these

failures may be interpreted as a noise-like interference. Such redundancy is found in the coding procedures and other means of checking built into the computer.

## CHECKING

Checking procedures assure accuracy in digital computers. Many different methods, for different reasons, are used:

- the parity check appends an extra digit, as needed, to the binary code for each character, so that all characters are represented by an odd (and therefore never zero) number of pulses. Thus, if any one digit is accidentally altered or if all of the digits are dropped, the error can be detected and the computation tried again automatically. Should the error persist, the computer sounds an alarm
- the echo check transfers the entire received information back into the source to see whether it is exactly the message that was sent
- a marginal check alters the heater supply and the B supply voltages in one section of the computer after another, thus exposing incipient failures, which might appear during computation
- mathematical checks, such as the substitution of the root of an equation back into the equation.

## ERRORS

Nearly all errors made during a computation are the fault of the human operator. The most experienced programmers seldom see a problem run correctly the first time. Debugging a program is a matter of successive approximations, during which the computer may be the undeserving object of a good many hard feelings. Once the program has been debugged, however, two other errors arise:

- quantizing error, resulting from round-off due to the limited number of figures that a computer handles, and
- truncation error, the result of the computer's limited (but high) speed.

### Quantizing Error

Quantizing, or round-off, error occurs because a continuous variable is being represented by a discrete succession of values, each of which can take on a limited number of different values. In digital computers round-off errors act like continuous noise. The effect builds up as long as the computation continues, rendering uncertain more and more of the digits at the least significant end of the numbers.

Thus, while ten digits seems adequate for a desk calculator, it is not so for an electronic digital computer, which executes so many more operations per final result that it often needs to carry additional digits. Because the quantizing error grows approximately with the square root of the number of arithmetic operations, the computer needs at least three more decimal digits than does a desk calculator.

### Truncation Error

Truncation error is due to the computer's limited speed, which necessitates representation of a continuous wave by a periodic succession of sampled values. Truncation error occurs principally in the solution of differential equations and in the computation of integrals and is a result of having to use a finite value for the increments of the independent variable.

In principle, one might use as small an increment as one pleased, but an increment one-fourth as large requires four times as many steps of integration. This would lead to four times as many round-offs and, on the average, twice as large an expected round-off error. Thus, the numerical analyst, when setting up the program for computer solution, balances carefully the effects of truncation and quantizing errors against the cost of computing time. This cost may suggest the acceptance of a large truncation error—thereby keeping down the total number of operations that a computer must perform.

### Error Analysis

But round-off errors are not necessarily independent and random; that is, they are not necessarily uniformly distributed between plus and minus half a unit in the last place. These errors may occur time after time in the same direction and build up to a larger total error. This situation must be guarded against carefully, for it may invalidate twice as many figures at the end of the result as would otherwise be expected. Thus, round-off errors limit the accuracy of the final result, just as the noise level limits the fidelity or the rate of transmission of information in a communication system.

## INFORMATION RATE

As we have seen, the input message becomes more and more corrupted by noise as the computation progresses. Thus, the effective signal-to-noise ratio at the output may be expected to be so much lower than the effective signal-to-noise ratio at the input as to be effectively independent of the latter. The output signal-to-noise ratio in any particular result may, therefore, be described as the ratio of that result (which should be of the order of unity) to its standard deviation. If the latter is due to random round-off errors, the signal-to-noise ratio, which may be defined as starting out after one arithmetic operation in a computer carrying  $n$  decimal digits, at about  $3 \times 10^n$ , on account of an assumed round off to  $n$  digits, will fall as  $t^{1/2}$  where  $t$  is the time, expressed in units of arithmetic operations contributing to the round-off error in the final result. If  $m$  digits of the final result are reliable and this result is close to unity (good scaling of the variables requires that the numbers be kept close to the maximum value that the computer can handle), the output signal-to-noise ratio may be about  $3 \times 10^m$ .

Without extensive use of mathematical theory of communication<sup>1</sup>, it is possible to see that as a communication channel between the input and the output, its informational capacity is  $m$  decimal digits per such result. Of course, under the guidance of a different program, the computer could have transmitted a vastly greater amount of information from the input to the output in the same length of time; e.g., it might simply have transferred input data directly to the output and done no computing. Thus, we see that any computing the computer does results in a loss of information!

This means that the result is implicit in the input program and input data and, in fact, a more exact result is implied by these data than the result obtained by the computer. A computer carrying more figures would have achieved a more accurate result. In fact, no computer at all is necessary. The programmer might have carried out his program (if he had enough time) with the aid of many pencils (and much paper) and obtained a result with arbitrarily great precision. A computer's real value is its speed in obtaining a result whose relationship to the input data is so obscure that the user of the computer can guess only very roughly what it will be. Thus, barring his resorting to other ways of estimating the result, the user, when he sees this result, gains a certain amount of information which is determined by the difference between his prior uncertainty as to the result, (expressed as the range of positions in which the first non-zero digit of the result will fall) and the number of digits of the computer's result in which he is interested or in which he places credence. Thus, the computer gives many decimal digits of information to the user for each successive result.

It is interesting to apply this approach to the case of the desk calculator, which may be slow enough for the operator to estimate the result fairly accurately before the machine has finished computing it. This ability of the computress to compute rapidly in her head reduces the amount of information the desk calculator gives her and it acts as a check against errors. The operator of an automatic computer, however, is not able to keep up with the machine unless he has laboriously computed a check solution in advance to make sure the computer is doing what he intends, and so he gets more information from the machine at the expense of uncertainty about the result's accuracy.

The point to be emphasized here is that the computer can in no case be regarded as generating information. The computer comes closest to doing that when it is executing a program for the generation of random numbers, but, actually, the numbers it generates are completely determinate, just as are all of the things an automatic computer does when it is operating properly. Hence, the user could generate the same "random" numbers by carrying out the computer program himself with paper and pencil. Although the numbers are not

really random and spontaneous, they may well possess the proper statistical characteristics that are required in their application. Furthermore, there are sometimes advantages to being able to repeat the same sequence of random numbers for use in a number of different computations.

The only time that a computer could be regarded as spontaneously generating information would be when the program guiding it is not known but the significance of the result is known. For this to happen, it would be necessary to have genuinely random elements entering into the creation of the program and, at the same time, an ability of the computer to explain the significance of its result. A computer vastly larger and more complex than any we have today would be required to realize such a generation of information by a computer, though it is not inconceivable that we shall one day have computers which are capable of a creativity comparable in degree with that of a human being.

## LEARNING

The ability to learn represents a lower form of intelligence than the ability to create, with which we have just dealt. Experiments have already been done with computers that learn to "adapt" to their environments, though the range of their responses to their environments so far has been rather limited. The computer is programmed to try out its various responses in a random order. Those responses that are rewarded by some measure of success (the computer must be told how successful it was in the situation with which it was confronted) it tries more frequently; those that are unsuccessful it tries less frequently. In this way, it can adapt its response pattern to a changing external environment, which represents a very rudimentary form of learning.

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MEYER LEIFER



N. M. BLACHMAN

## HOW STABILIZATION IMPROVES CLOSED-LOOP OPERATION

# Putting Stabilization To Work

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**THE GIST:** Last month the authors expressed the operation of closed-loop systems in terms of stability and damping. Now they describe actual stabilizing and damping techniques that can improve the dynamic operation of servos. Network stabilization, one of the most frequently used methods, is considered at length. Normally, these corrective networks are designed for a dc servo. But they are easily converted to an equivalent ac circuit for use in an ac servo. Two tables in the article show the steps for designing a dc stabilizing network and for converting it. A third table illustrates eight other ways to improve servo operation. This latter table includes brief descriptions, advantages and disadvantages, and illustrates each device or circuit.

As a final practical contribution, the authors apply the damping network to a synchro-type repeater servo. They work out the transfer function of the uncorrected servo; determine the corrective positive phase shift; design the network to give this shift; compute the values of the resistance, capacitance, and inductance; and indicate two different ways to use this circuit in the ac servo.

## STABILITY AND DAMPING

A servo system requires adequate stability and damping, characteristics that depend on such dynamics as amplifier gain, motor and load inertia, and friction. Often a system must be adjusted to meet design requirements. Generally, the major adjustment is made by:

- introducing a positive phase shift angle to partially compensate excessive negative phase shift of the open-loop transfer function of the system, or
- increasing the effective friction in the system.

Probably the most advantageous procedure involves network stabilization, properly designed combinations of resistance, inductance, and capacitance giving the necessary positive phase shift. This approximates true error-rate damping, and will be discussed in detail along with a practical example.

However, the many ways to adjust the effective

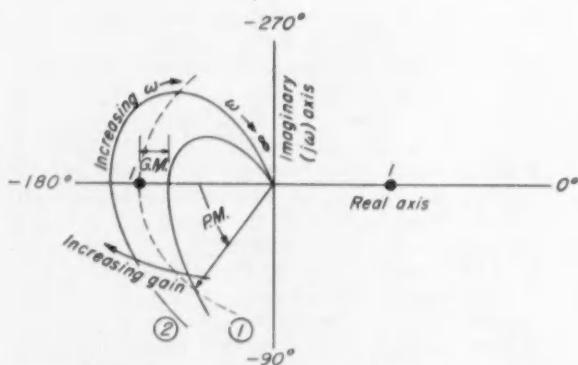
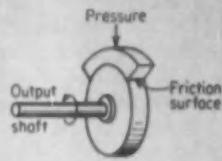
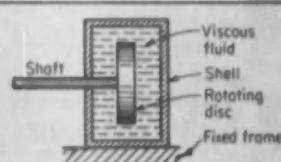
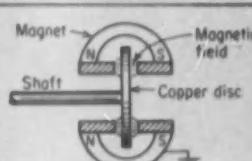
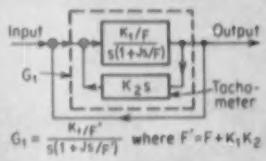
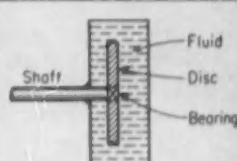
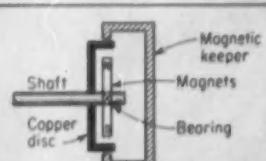
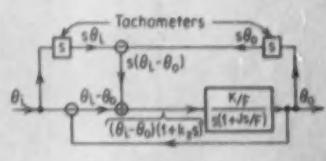
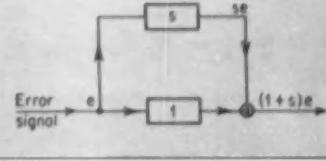


FIG. 1. Typical Nyquist plots of an open-loop transfer function, useful in determining the relative stability of a closed-loop system. Because the system is third-order, the curves asymptotically approach the minus 270 deg axis as the magnitude falls to zero. Curve 1 represents a stable system—it does not enclose the 1  $\angle$  -180 deg point. Curve 2 shows instability—it encloses the point. Phase margin (PM) and gain margin (GM) show relative stability—both are positive. When gain increases, they become negative and servo is unstable.

TABLE I EIGHT WAYS TO IMPROVE SERVO OPERATION

| THE METHOD  | CONSIDERATIONS   | DEVICE  |
|---|--|---|
| 1. COULOMB FRICTION obtains from suitable friction surfaces on the output shaft. The resulting force opposes the shaft motion. A dead zone exists where small oscillations are permitted.   | Inexpensive and simple, where accuracy requirements are not important. But wear limits life; difficult to adjust and maintain; wastes output power; and introduces static and velocity positional errors.    |    |
| 2. FLUID VISCOS DAMP increases effective friction. Shaft rotates disc inside a cylindrical shell filled with viscous fluid. Rotating disc exerts restraining torque proportional to velocity.   | Simple, rugged, has long life. Large F coefficient obtainable in small size. But adds inertia to motor rotor. Fluid may leak; fluid viscosity may be temperature sensitive; and some output power is wasted. |    |
| 3. EDDY CURRENT DAMP gives same effect as 2, but uses magnetic construction. A copper disc rotates perpendicular to a magnetic field. Induced eddy currents set up magnetic field, and exert retarding force.   | Easily assembled; there's no fluid to leak out. Good reliability; but inertia added to motor. For given size the damping is limited; temperature varies resistance of disc and hence damping.                |    |
| 4. VELOCITY FEEDBACK gives voltage signal from tachometer proportional to output shaft velocity. This arrangement increases effective friction coefficient.   | No large power waste; and coefficient F easily adjusted by voltage divider or transformer at tach output. But may be expensive, and of relatively large size; extraneous electrical noise may be present.    |   |
| 5. VISCOUS ACCELERATION DAMP is similar to 2, but shell fixed to shaft and disc free to rotate. On sudden velocity changes inertia of disc gives restraining torque proportional to difference in relative velocity between shaft and previous disc speeds. | Energy dissipation only when motor suddenly changes speed, and no additional velocity error is introduced. However, heavy disc increases system inertia, and bearings are difficult to manufacture.          |  |
| 6. MAGNETIC ACCELERATION DAMP gives same effect as 5. Construction similar to 3, again disc is free to rotate. At sudden velocity changes the device creates a torque proportional to difference in relative velocity.                                      | No additional error introduced; energy dissipated only during acceleration. But strength of magnet limits damping torque; and device adds inertia to motor rotor.  |  |
| 7. TRUE ERROR-RATE derives from two tachometers that give velocity difference between input and output. Overall effect introduces $(1 + k_3)$ term in numerator of system transfer function to give corrective (positive) phase shift.                      | Arrangement gives ideal correction, but requires two matched tachometers to get rate signals of input and output velocities. Also needs additional comparators to obtain difference voltages.                |  |
| 8. ALTERNATIVE ERROR-RATE method adds derivative (lead) signal to error signal and gives positive phase shift. This improves phase and gain margins.  | Block S might be dc operational amplifier. But this requires vacuum tubes and power supplies.  |  |

friction also have their uses. Table 1 includes these methods, illustrates typical devices, and points out their advantages and disadvantages. In addition, this table includes error-rate damping methods other than stabilization networks.

A Nyquist plot (Figure 1) shows the frequency response of the open-loop transfer function of a third-order servo. This diagram discloses several bits of useful information about the operation of the system when the loop is closed. Among these points:

- whether or not the system will be stable, and
- if the system is stable, whether there is enough margin of stability to assure adequate performance under all conditions

A single-loop servo is stable if the open-loop transfer function does not enclose the point  $1 \angle -180$  deg when plotted on the Nyquist diagram, as in Figure 1. Here, phase margin and gain margin indicate the extent of stability.

The amount of damping determines the response of the closed-loop system to transient disturbances. Proper damping assures fast response, usually with one or more overshoots as the output seeks the position commanded by the input.

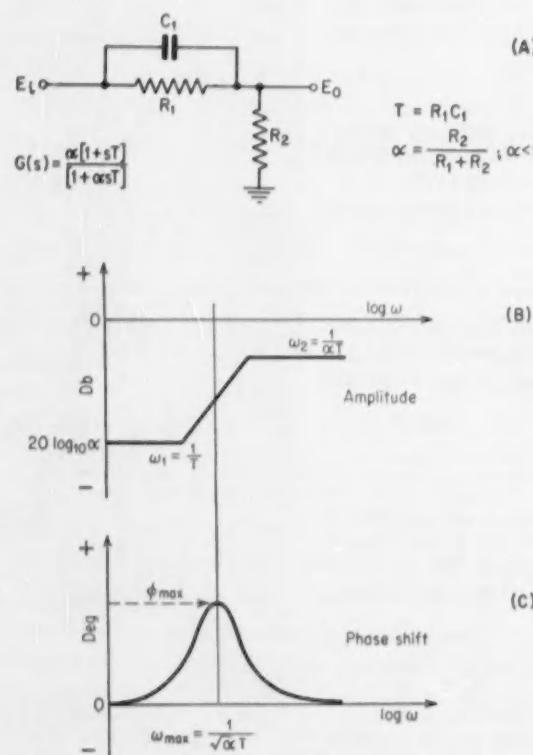


FIG. 2. A dc lead network (2A) uses a combination of resistance and capacitance to obtain the rising amplitude (2B) and positive phase shift (2C) that characterize a lead network.

## STABILIZATION TECHNIQUES

Improved stabilization and damping result from three major techniques:

► Coulomb friction—here, a constant mechanical force opposes the motion of the output member. This type of friction is essentially independent of the velocity of the output, but may have a dead zone that allows oscillations of small amplitude, which may be desirable. Undesirable, however, is wasted power at the output, and a constant uncertainty in position due to coulomb friction. Coulomb friction is shown in Table 1.

► Velocity damping—this method develops a force proportional to the velocity of the output and opposes the output motion. Velocity damping may waste output power, and also introduce a positional error. This method of damping can be developed in several ways, as shown in Table 1:

- fluid viscous damping (mechanical)
- eddy current damping (magnetic)
- velocity feedback (electrical)

► Error-rate damping—in this case, an ideal arrangement would combine the error signal with its rate of change and develop a force opposing the output motion. The rate of change introduces a positive phase shift angle in the through loop that helps to offset some of the negative (lag) angle produced by the motor and load. Error-rate damping eliminates velocity errors and does not waste output power. Table 1 lists the several ways to obtain error-rate damping:

- viscous acceleration damping
- magnetic acceleration damping
- electromechanical (two methods)

Networks provide a nearly ideal error-rate damping and have certain advantages over some of the above methods.

## DC AND AC SERVO SYSTEMS

Servo systems divide into two categories with respect to their power source:

► dc servos use dc voltages as their power source. But the instantaneous value of the actuating signal varies with time, as in the case of periodic changes in the input amplitude during a frequency-response test.

► ac servos, on the other hand, use a high-frequency carrier voltage (60 or 400 cps) as the source of power. Here the lower-frequency actuating signal amplitude-modulates the carrier. But the system responds only to the envelope of the modulated wave.

Frequency response of ac and dc systems are plotted in identical ways, for only the information—carrying, or modulating signals are of interest in checking stability and damping on a Nyquist diagram, and the dc source and the high-frequency carrier voltages are extraneous. The circuits for particular transfer functions, however, differ for ac and dc servos.

TABLE 2

FACTORS IN DESIGNING A LEAD NETWORK

| THE REQUIREMENTS  | THE CHOICE | WITH THESE CONDITIONS   |
|---|------------|---|
| INPUT IMPEDANCE TO AMPLIFIER                                  | $R_2$      | $R_2$ will be the minimum input impedance to the amplifier at the highest frequency.  |
| MAXIMUM LEAD ANGLE — $\phi_{max}$                             | $R_1$      | $\arcsin \phi_{max} = \frac{1 - \alpha}{1 + \alpha}$ , where $\alpha = \frac{R_2}{R_1 + R_2}$ .<br>Then pick $R_1$ , since $R_2$ is known.                            |
| FREQUENCY AT WHICH MAXIMUM LEAD ANGLE OCCURS — $\omega_{max}$ | $C$        | $\omega_{max} = \frac{1}{\sqrt{\alpha} T}$ where $T = R_1 C$ ,<br>$\alpha$ and $R_1$ known. $T$ determined from $\omega_{max}$ and then $C$ from time constant, $T$ . |

## DC LEAD NETWORKS

The resistance-capacitance combination shown in Figure 2A produces a positive phase shift as required from a lead network. In fact, this widely used circuit serves as a prototype for many other types. Here, the transfer function,  $G(s)$ , equals the output voltage,  $E_o$ , divided by the input voltage,  $E_i$ , or

$$G(s) = \frac{E_o}{E_i} \quad (1)$$

where  $s$  equals  $j\omega$ , the frequency variable.

$$G(s) = \frac{R_2}{R_2 + \frac{R_1}{1 + sCR_1}} \quad (2)$$

$$= \frac{R_2(1 + sCR_1)}{R_1 + R_2 + sCR_1R_2} \quad (3)$$

$$\text{Let } \alpha = \frac{R_2}{R_1 + R_2}$$

and let  $T = R_1 C$ ; then factor  $R_1 + R_2$  from the denominator of Equation 3; the transfer function becomes:

$$G(s) = \frac{\alpha(1 + sT)}{1 + \alpha sT} = \frac{\alpha(1 + j\omega T)}{1 + \alpha j\omega T} \quad (4)$$

The frequency response of this network is shown in the Bode diagram (Figures 2B and 2C) as determined from Equation 4 (see *How Stabilization Improves Closed-Loop Operation*, Vol. 2, No. 12). Figure 2C indicates that a positive phase shift, or phase lead, occurs over a large range of frequencies. This phase lead compensates excessive phase lags originally present in the servo. The maximum phase lead,  $\phi_m$ , is found from the relation:

$$\phi_m = \arcsin \frac{1 - \alpha}{1 + \alpha}$$

and occurs at the geometric mean of the two break point frequencies of the transfer function,

$$\omega = \frac{1}{\sqrt{\alpha} T}. \text{ Here the break frequencies are } \omega_1 = \frac{1}{T}$$

and  $\omega_2 = \frac{1}{\alpha T}$ , and their geometric mean is the square root of the product of the two frequencies.

The foregoing relationships can be grouped for further reference in the design and use of R-C type lead networks. This is shown in Table 2.

The circuit of Figure 2A gives a modified form of error-rate damping. True error-rate damping has a transfer function of the form:  $(1 + sT)$ , as in the numerator of Equation 4. But this true form is modified by the factor  $(1 + \alpha sT)$  in the denominator. The denominator term offsets the benefits of the true lead that results from the term in the numerator. Figure 2C shows that the phase lead decreases to zero at the higher frequencies.

The lead network operates on the error signal. However, the attenuation ( $\alpha < 1$ ) introduced by the network needs increased amplifier gain ( $1/\alpha$ ).

Another form of dc lead network (Figure 3) uses inductance instead of capacitance, but gives an equivalent transfer function. Here resistor  $R_2$  includes the coil resistance of the inductance.

## AC LEAD NETWORKS

The amplitude and phase shift characteristics for an ac lead network (Figure 4) show symmetry around the carrier frequency. There is a similarity between these characteristics for ac and dc lead

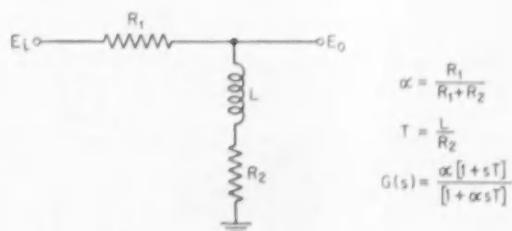
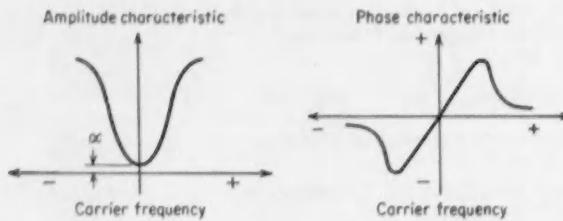


FIG. 3. An alternative circuit uses resistance and inductance to obtain the characteristics required of a lead network.

FIG. 4. The amplitude and phase shift curves of an ac lead network are symmetrical about the carrier frequency, but are similar to the dc lead network.



networks: the characteristics to the right of the carrier frequency in Figure 4 are equivalent to the characteristics in Figures 2B and 2C.

In general, the ac lead network characteristic is similar to a band-pass rejection filter about the carrier frequency. The shape of the amplitude characteristic of Figure 4 led to calling this type of circuit "notch" networks.

There are several ways<sup>1</sup> to develop the characteristics of Figure 4. One is the tuned resonant circuit (Figure 5). The derivation<sup>1</sup> of its transfer function is particularly interesting. At first the analysis includes the carrier frequency, but later this is eliminated because only the modulating frequency (much lower than carrier) is needed to determine stability, as shown on a Nyquist or Bode diagram.

The ratio of output to input voltage (transfer function) of this circuit is:

$$\frac{E_o}{E_i} (j\omega) = \frac{R_2 + j\omega L + \frac{1}{j\omega C}}{R_1 + R_2 + j\omega L + \frac{1}{j\omega C}} \quad (5)$$

and the final result, in terms of  $\omega_m$ , the modulating frequency, becomes:

$$\frac{E_o}{E_i} (j\omega_m) = \frac{\alpha \left( 1 + \frac{2L}{R_2} j\omega_m \right)}{1 + \alpha \frac{2L}{R_2} j\omega_m} \quad (6)$$

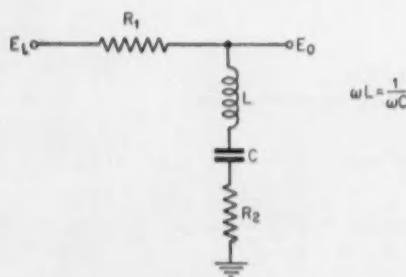


FIG. 5. A tuned resonant lead network typifies one of the many circuits that gives the characteristics of Figure 4.

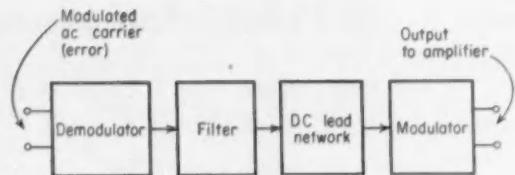
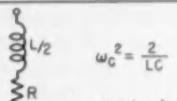
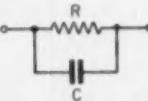
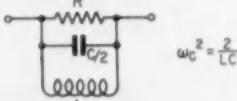


FIG. 6. An ac servo uses a dc lead network by demodulating the modulated ac carrier signal (error signal), passing it through a filter, applying the new signal to the stabilizing network, and then remodulating and amplifying the corrective signal.

Equation 6 shows a similarity to Equation 4. The transfer function of the ac lead network is equivalent to the dc lead network, except that a capacitor tunes the inductance to the carrier frequency and its time constant corresponds to  $2L/R$ . This equivalence leads to a conversion procedure, as shown in Table 3.

The derivation of the ac lead network transfer function assumes that the carrier frequency coincides with the network center frequency, and that the motor fields are 90 electrical deg apart at the carrier frequency. A variation in these conditions partially destroys the damping properties of the network. Good operation calls for low drift of the carrier frequency and close tolerance on the motor field alignment. Other disadvantages of this circuit: harmonics are emphasized, inductance must be linear, and the inductance pickup of the carrier frequency introduces extraneous effects. However, ac lead networks are practical for many servo applications.

One way to overcome these drawbacks of ac lead networks involves a demodulator-modulator arrangement with a dc lead network. Figure 6 shows a block diagram of the method. Here the modulated ac carrier is first demodulated and then fed to an appropriate filter. The resultant signal, the envelope of the modulated carrier, is acted on by the dc lead network to obtain stabilizing action. Then, the modulator recombines the modified signal with the carrier frequency and sends it to the ac amplifier.

| TABLE 3 AC-DC LEAD NETWORK CONVERSION   |   |
|---|---|
| DC elements   | Equivalent AC elements  |
|  |  |
|  |   |

# HOW A NETWORK SOLVES A DAMPING PROBLEM

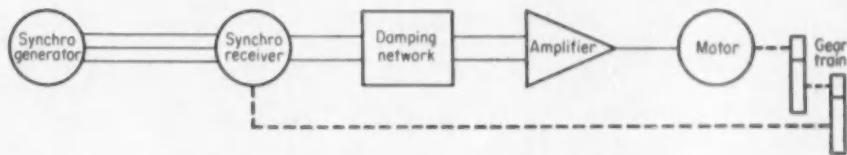


FIG. 7. A repeater-servo illustrates design of a corrective lead network. Although the servo is ac, the damping network is designed on the basis of a dc servo. The dc lead network can be used with a demodulator-modulator arrangement, or converted to an ac lead network.

A synchro-type repeater servo illustrates the network method of improving system performance. The block diagram in Figure 7 shows this type of servo. It is assumed here that all components except the damping network have been designed to meet a given set of specifications:

|                             |  |
|-----------------------------|--|
| Carrier frequency           | 400 cps                                  |
| Servo natural frequency     | 20 cps                                   |
| Servo motor (Kearfott R110) |  |
| rotor inertia               | $1.13 \times 10^{-8}$ lb-in <sup>2</sup> |
| stalled torque              | 1.45 in.-oz                              |
| no load (rated) speed       | 5000 rpm                                 |
| Load inertia                | assumed negligible                       |

**THE PROBLEM:** evaluate the system without the damping network, and from this information design a suitable corrective network.

The transfer function of the open-loop system is considered as second-order and represented by:

$$G(s) = \frac{A}{s(1 + T_m s)} \quad (7)$$

where  $A$  = the overall open-loop gain constant, and  $T_m$  = the mechanical time constant of the motor

Both of these constants are unknown, and must be derived to determine the frequency response of the uncorrected servo.

## The Gain Constant

Consider that the system is in equilibrium and that the motor shaft is twisted to a constant displacement of one radian. The amplifier then exerts a torque on the motor shaft. The magnitude of the torque is found from the relationship:

$$\omega_n = \sqrt{K/J} \quad (8)$$

where  $\omega_n$  = the natural frequency of the system (20  $\times 2\pi$  radians)

$K$  = the torque per unit angle (in.-lb/rad)

$J$  = the total inertia referred to the motor shaft (lb-in.<sup>2</sup>)

From the above specifications:

$$K = 0.0465 \text{ in.-lb/rad}$$

The overall gain constant is found from this relationship:  $A = K/F$

$$\text{where } F = \frac{\text{rated torque}}{\text{rated speed}} = 1.73 \times 10^{-4} \frac{\text{in.-lb}}{\text{rad/sec}} \quad (9)$$

Thus,  $A = 269/\text{sec}$ .

## The Time Constant

The time constant equals

$$T_m = J/F = 0.017 \text{ sec}$$

However, the non-linear characteristic of the motor indicates that the time constant for low voltage should be about twice the calculated value, or 0.035 sec. It is advisable to use this higher value.

## The Open-Loop Transfer Function

The numerical form of the transfer function becomes, as a result of the preceding analysis:

$$G(s) = \frac{269}{s(1 + j0.035s)} \quad (11)$$

This corresponds to a break frequency of:

$$f_1 = \frac{1}{2\pi \times 0.035} = 4.6 \text{ cps} \quad (12)$$

and a magnitude, at this frequency, of:

$$G(f_1) = \frac{269}{2\pi \times 4.6 \times \sqrt{2}} = 6.7 \approx 16.5 \text{ db} \quad (13)$$

By trial and error, the frequency at unity gain is equal to 13.6 cps; its phase lag is calculated thus:

$$\begin{aligned} \theta &= (90 + \arctan 0.035 \times 2\pi \times 13.6) \text{ deg} \quad (14) \\ &= (90 + 72) = 162 \text{ deg} \end{aligned}$$

Hence, by definition, the phase margin of the open-loop system without the damping network is

$$\phi = 180 - 162 = 18 \text{ deg} \quad (15)$$

Optimum performance calls for a phase margin somewhat greater, perhaps 40 to 60 deg.

## Lead Network Design

The lead network should give the maximum phase lead at the frequency of unity gain for the overall compensated system. This frequency is determined by trial and error, and is most easily accomplished on a Bode diagram. The amplitude characteristic of the network alone and the amplitude of the system with this network inserted are both plotted. The geometric frequency of the assumed network is shifted until it coincides, roughly, with the frequency at which the overall system has unity gain.

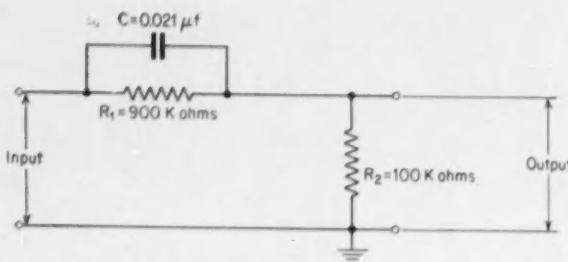


FIG. 8. The analysis of the servo in Figure 7 leads to the above suitable dc lead network, and may be applied with a demodulator and modulator.

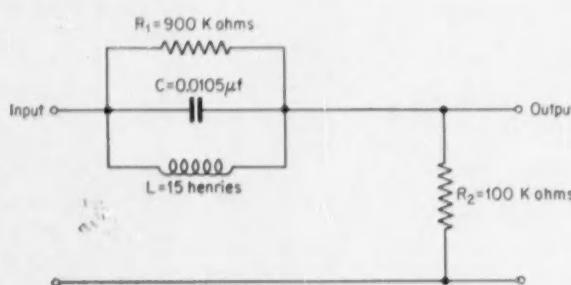


FIG. 9. If the corrective network characteristics for the repeater servo of Figure 7 must be obtained from an ac circuit, Table 3 can be of aid. It facilitates conversion of the dc lead network of Figure 8 to the tuned resonant circuit shown in the above cut.

Using this technique, the low frequency break point of the network for the above system results in about 8.5 cps. Then the time constant becomes:

$$T = \frac{1}{\omega_1} = \frac{1}{2\pi \times 8.5} = 0.0187 \text{ sec} \quad (16)$$

For these lead networks, an attenuation factor of 0.1 is usually practical; hence,  $\alpha = 0.1$ . The transfer function of the network to improve the damping of the above servo is given by:

$$G(s) = 0.1 \frac{(1 + 0.0187s)}{(1 + 0.00187s)} \quad (17)$$

But to realize the benefit of the damping network the gain of the servo amplifier must be increased by 10. The overall transfer function of the servo system then is:

$$G(s) = \frac{269}{s(1 + 0.035s)} \frac{(1 + 0.0187s)}{(1 + 0.00187s)} \quad (18)$$

From a plot of Equation 18 it is found that at a frequency of 23.5 cps the gain is unity, or 0 db. The phase lag at this frequency is equal to:

$$\theta = (90 + \arctan 5.18 + \arctan 0.276 - \arctan 2.76) \text{ deg} = (90 + 79 + 15 - 70) = 114 \text{ deg}$$

Hence the phase margin with the lead network is equal to

$$\phi = 180 - 114 = 66 \text{ deg}$$

This represents an increase in phase margin of:

$$\Delta\phi = 66 - 18 = 48 \text{ deg}$$

due to the insertion of the lead network. Thus a significant improvement in the dynamic response and overall stability of the servo has been effected by means of the lead network.

The actual network may now be designed with reference to Figure 2 and Table 2. Assume that the desired minimum input impedance,  $R_2$ , is 100,000 ohms. Then:

$$R_1 = R_2 \left( \frac{1 - \alpha}{\alpha} \right) = 900,000 \text{ ohms}$$

$$C_1 = \frac{T}{R_1} = \frac{0.0187}{0.9 \times 10^6} = 0.021 \text{ microfarads}$$

Hence the dc lead network required is as shown in Figure 8.

Because specifications call for an ac carrier type servo, the dc lead network shown in Figure 8 must be used with a modulator-demodulator circuit as indicated in Figure 6. If, however, an ac type network is desired, a design can be effected quickly by means of Table 3. Considering the shunt resonant circuit, the value of inductance is calculated by the following relationship:

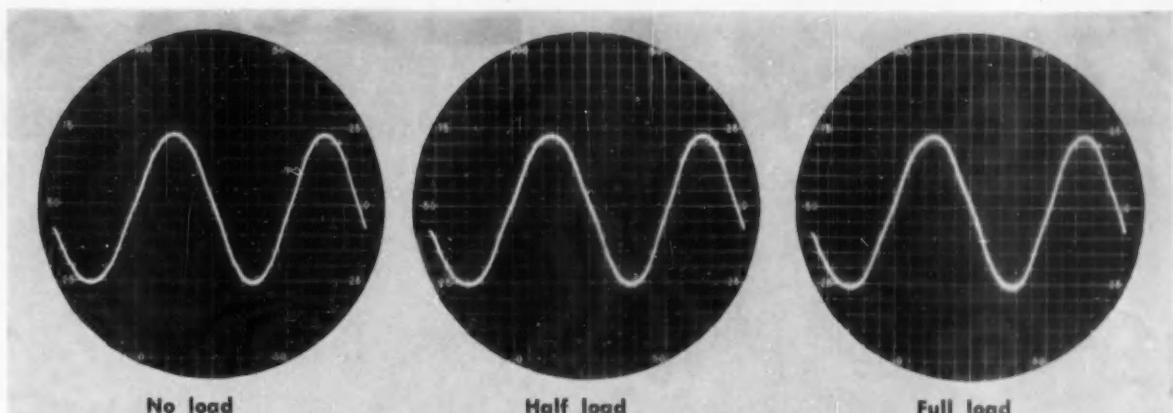
$$L = \frac{2}{\omega_0^2 C} = \frac{2}{(400 \times 2\pi)^2 \times 0.021 \times 10^{-6}} = 15 \text{ henries}$$

and the ac carrier-type lead network is that pictured in Figure 9.

Practical application calls for some adjustment in either  $C$  or  $L$  so that the shunt resonant circuit can be accurately tuned to the carrier frequency. This results in optimum performance. The equivalent response of the ac carrier network only approximates that of the dc network—there may be some noticeable differences in the servo dynamic characteristics between the two systems, especially as the servo bandwidth increases relative to the carrier frequency. This effect is difficult to evaluate, and in most practical cases appears to be either small or negligible.

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3. PRINCIPLES OF SERVOMECHANISMS, Gordon S. Brown and Donald P. Campbell, John Wiley & Sons, Inc., 1948.
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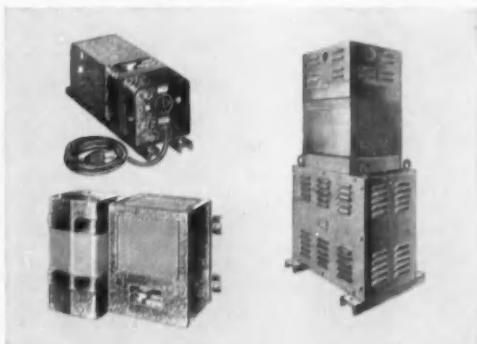
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| *TYPICAL HARMONIC ANALYSES, TYPE CVH<br>CONSTANT VOLTAGE TRANSFORMER |                |                 |       |       |       |
|--|----------------|-----------------|-------|-------|-------|
|  | Input<br>Volts | Output<br>Volts | 3rd   | 5th   | 7th   |
| Full Load  | 115            | 115.0           | 0.77% | 1.20% | 0.34% |
| 50% Load   | 115            | 116.1           | 1.00  | 0.70  | 0.55  |
| No Load  | 115            | 116.2           | 0.65  | 0.36  | 0.60  |

*\*On production units, the lowest residual harmonic content may occur anywhere between full load and no load.*



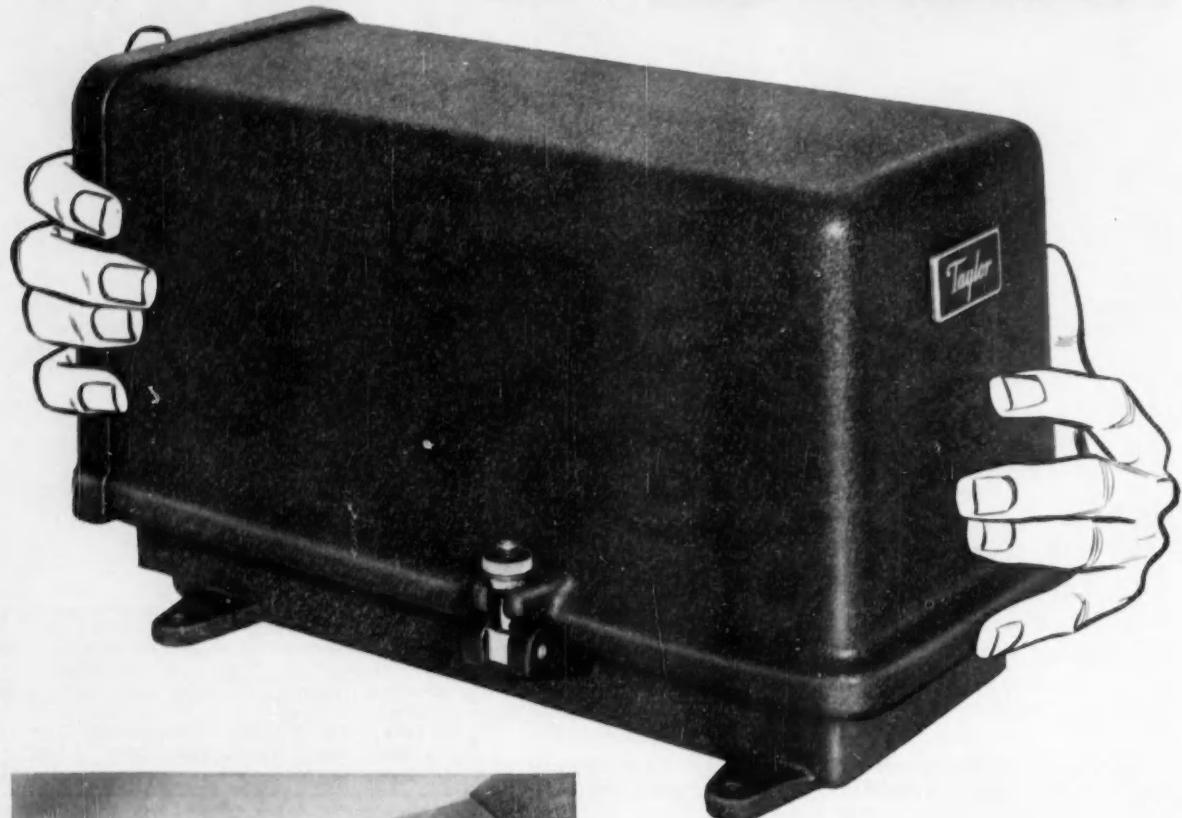
**TYPICAL MECHANICAL STRUCTURES:** The two stabilizers on the left are stock units, the transformer on the right is a "special" in the 7,500va size range.

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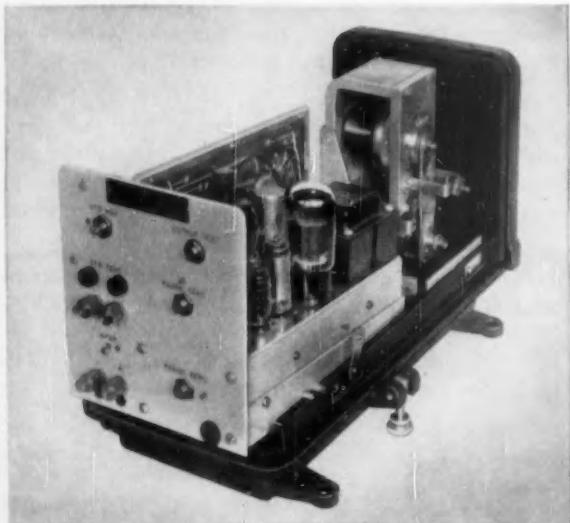
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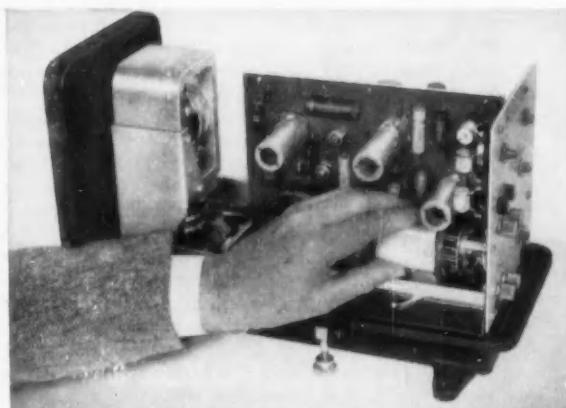
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**Write for Bulletin #98262.** Taylor Instrument Companies, Rochester, N.Y., and Toronto, Canada.

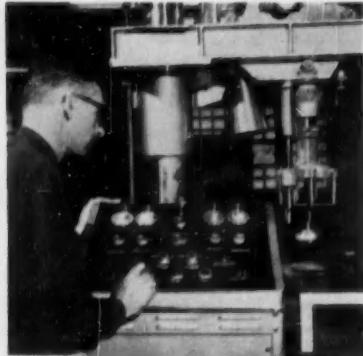
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— MEAN —  
**ACCURACY FIRST**

**IN HOME AND INDUSTRY**

## IDEAS AT WORK

# Knob-Controlled Servos Speed and Simplify Panel Drilling

The man at the console below is putting the large traveling drill through some fairly complex hole-cutting routines by merely dialing in coordinates and commands.

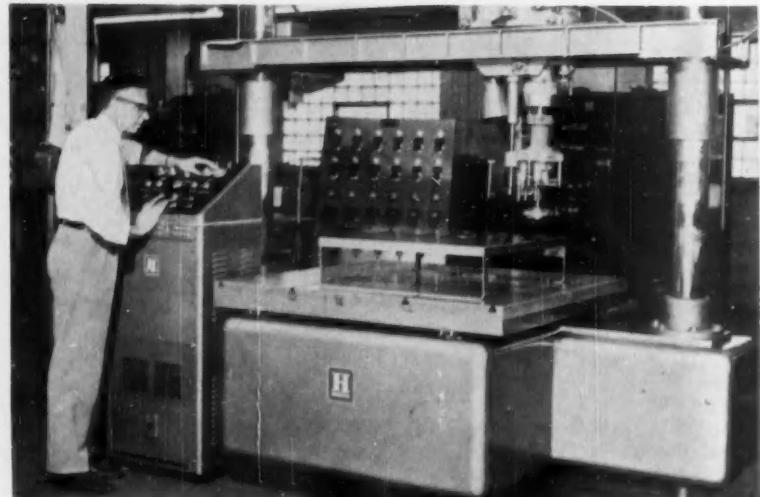


The four knobs on top locate workpiece and drill, set hole coordinates. Pushbuttons control sequence, rpm, jog, reset.

**JOHN J. RUDOLF**  
Minneapolis-Honeywell Regulator Co.

Industrial control panels are usually custom tailored. Hence, cutting various-sized holes for instruments, dials, starters, etc., has necessarily been a tedious manual operation: the layout, checking, center-punching, and drilling of each hole in the  $\frac{1}{4}$ -in. steel sheet consume an average of about 5 min per hole. Further, though hole tolerances are not critical, the process of fashioning a panel is subject to human error every step of the way.

In order to substantially reduce cutting time and the chance for human error, engineers of Minneapolis-Honeywell's Machine Controls Div. have designed an automatic drilling machine that makes cutting holes as easy as tuning a TV set. Starting with a special machine built by Farwell Metal Fabricating Co. of St. Paul, they added automatic controls that enable an operator to "dial" the X and Y coordinates of a desired hole



The machine, built to design by a St. Paul fabricator, consists of a traveling drill head mounted over a movable table. Its multiple spindle head can drill five holes at one time and cover a 4 ft by 4 ft area. A completed panel is in the background.

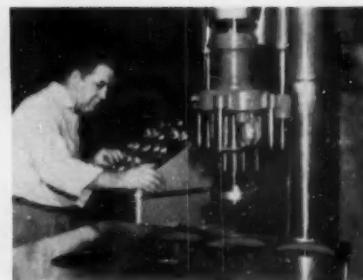
and then drill it by merely pressing a button.

### MACHINE DETAILS

Basically, the Honeywell drilling machine consists of a traveling drill head mounted over a movable table. Both table and head can travel 4 ft in perpendicular directions and can thus

machine any point in a 4 ft by 4 ft area. Larger panels—8 to 10 ft long and up to 6 ft wide (limited by the throat of the machine)—can be drilled in several steps. The drill spindle travel of 4 in. is adequate for all drilling operations and the entire head and cross rail assembly can be raised or lowered to handle various panel heights.

The machine's drill spindle is driven by a ELC3J thyatron-controlled variable speed motor for optimum spindle speeds for drills as small as  $1/32$  in. Also, a belt reduction makes it possible to saw or fly-cut large holes up to 6 in. in diam at speeds as low as 3 rpm. The drill head itself is equipped with a multiple spindle attachment that can drill up to five holes simultaneously. For example, the clearance and mounting holes for a pressure gage can be machined in one pass by attaching a hole saw in the center spindle and the required number of small drills in the adjustable spindles. Simultaneous drilling becomes particularly useful when several identical components are to be mounted on a



### ONE JOB IT DID

In this typical panel job the large holes were cut with the hole saw (shown) and the three-hole groups were cut in one pass by two drills and a smaller hole saw.

panel. Actually, the idea of using a "memory" to handle duplicated holes with a single spindle was considered first—but was rejected in favor of the far less complex mechanical method.

#### SYSTEM ACCURACY

As the control system diagram and its description might indicate, the inherent positional accuracy of the measuring system is not high enough for final hole location since errors are

present in the lead screws, feedback potentiometers, and associated gearing. However, a desired over-all accuracy was achieved by calibrating the positioning systems against accurate length bars and adjusting the input voltage dividers to compensate for major nonlinearity errors. The resulting positional accuracy is within a desired 0.005 in. and repetitive accuracy approximately one half of this.

While the locating accuracy of this

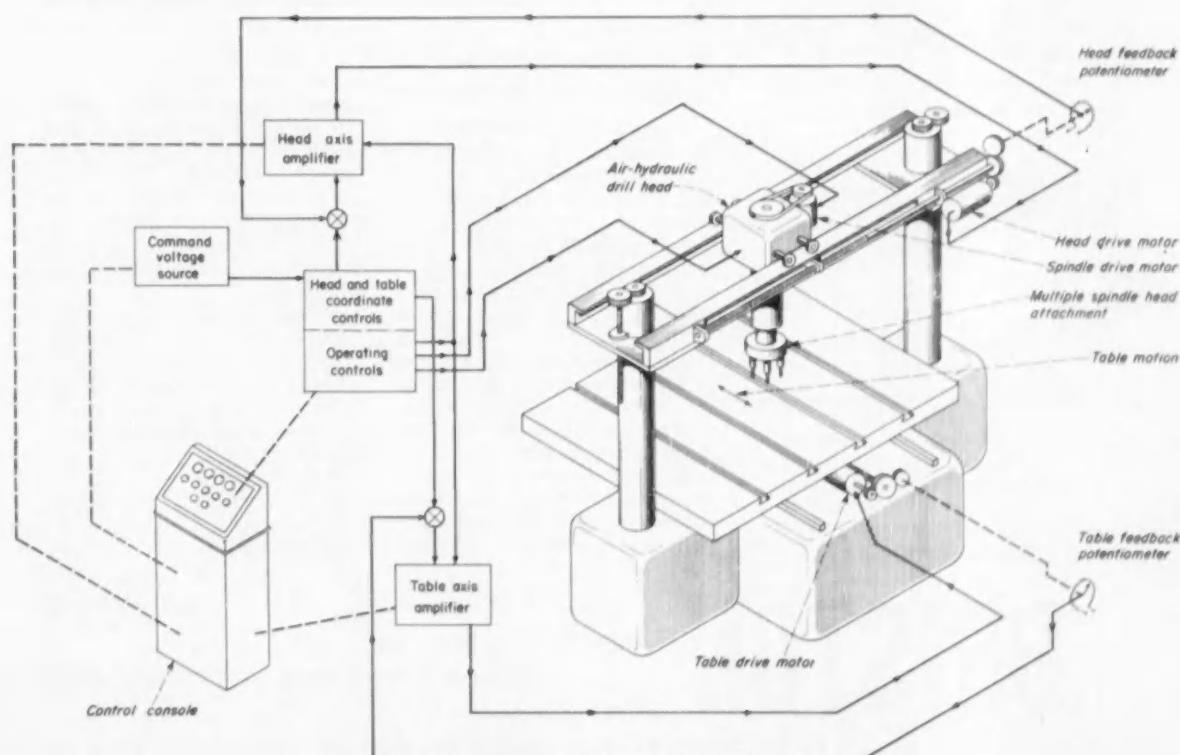
machine is quite adequate for panel board work, the use of more precise measuring systems would place it into the category of a "poor man's automatic jig borer". If required, punched card or tape control could be readily applied for more automatic operation. Tape or card preparation would be completely straightforward since simple hole coordinates, rather than complex tool paths, form the basis for all machine instructions.

### HOW THE DRILLING CONTROL SYSTEM WORKS

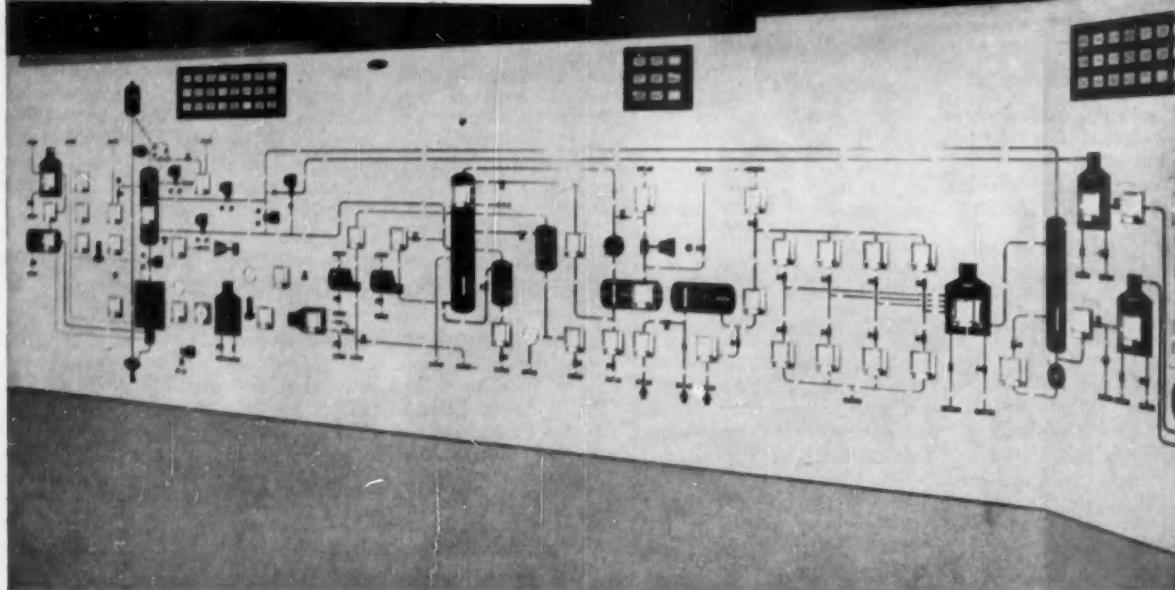
In the simplified diagram below, the drill head and table are positioned by conventional positional servomechanisms comprising thyratron amplifiers, ac servo motors, and feedback potentiometers. Inputs to the two servo loops are taken from precision resistive voltage dividers. Voltages from the latter—representing 0 to 48 in. to the nearest 0.001 in.—are knob-selected at the console. The two dc input voltages are compared with their respective feedback voltages, converted to 60 cycle ac signals, and fed into two relay amplifiers. The latter set the desired error thresholds and determine when the servo systems have positioned to within the required tolerance band. The error signals are also channeled to the thyratron power amplifiers, summed with their respective tachometer feedback signals, and used to control the combination ac/dc bias on the thyratron grids. The two servo loops are stabilized by a combination of ac tachometer feedback and error rate compensation in the dc bridge circuits. Dc was chosen for bridge voltage also, to avoid noise and quadrature problems often found in complex

ac signal circuits. Additional controls permit jogging all machine motions, selecting spindle rpm, sequencing drilling operations, and choosing constant feed or constant thrust drilling.

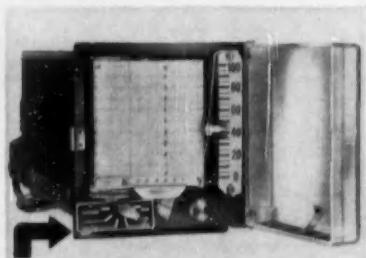
In the case of single operations reset controls return the head and work-piece to a location convenient to the operator. Indicator lights show the position of the head and table relative to the called-for position. They allow the operator to pinpoint the location of any reference point on the workpiece with respect to machine coordinates. Hence, the operator does not have to locate the panel accurately on the table; he simply determines where he has placed it in terms of the machine's coordinate system. To do this he jogs the head and table until the spindle is aligned with some reference point on the panel and then adjusts the input selectors until the indicator lights show that the positions called for coincide with those that exist. By correcting all hole coordinate instructions by the amount of these initial settings, he can proceed without aligning the panel.



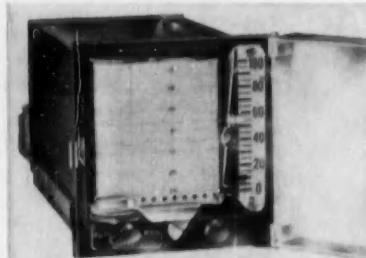
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$$= \sqrt{2} B \sin \omega_0 t [A \sin \theta_0 - \frac{A}{n} \sin n\theta_0]$$

The transition from fine to coarse data begins when the peak value of  $e$  equals the Zener voltage  $E_z$ .

$$E_z = \frac{\sqrt{2} BA}{n} (n \sin \theta_0 - \sin n\theta_0)$$

where  $\theta_0$  is the switching angle.

The switch from fine to coarse data should be made before the fine data has reached its peak and begins to

decrease:  $50 \text{ deg} < n\theta_0 < 70 \text{ deg}$ . For this value of  $n\theta_0$ ,  $(n \sin \theta_0 - \sin n\theta_0) \approx 0.25$ .

$$E_z \approx \sqrt{2} \frac{BA}{4n}$$

The data-speed ratio  $n$  depends on particular requirements of the data system. The type of synchro selected fixes the synchro sensitivity  $B$ . These two parameters then determine the gain  $A$  and Zener voltage  $E_z$  of the

diodes. Typically,  $E_z$  may be any voltage above about 5 v. Gains  $A$  that may be expected for  $E_z$  in this range will run 10 to 25, readily realized by a single triode voltage amplifier stage.

Figure 3 is a typical switching curve for a 10-speed system with a diode Zener voltage of 5 v. The transition is smooth and the ultimate one-speed gain is the same as in the fine data control zone.

## Integrator Computes Tristimulus Values

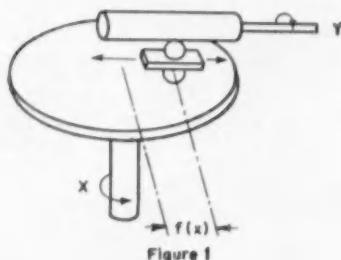


Figure 1

The basic component of the Automatic Tristimulus Integrator is the analog ball and disc integrator, above. At right is the schematic of the ATI's mechanical circuit, which evaluates integrals of the illumination source's spectral distribution.

The measurement of color, like the measurement of other complicated phenomena, lends itself to simplified procedures when the underlying principles are reduced to their basic components. Once the basic components, or tristimulus values, of color are obtained, a unique definition of the color of an object results.

However, each of the tristimulus values requires integration, an operation complicated by the factors inside the integral, themselves functions of wavelength. As pointed out by O. H. Olson in Part I of *Color Basics for the Control Engineer* (CONTROL ENGINEERING, October 1955, page 78) these integrals do not lend themselves to simple evaluation and must be performed graphically or mechanically. The Automatic Tristimulus Integrator (ATI) developed by Librascope, Inc., for use with the GE Re-

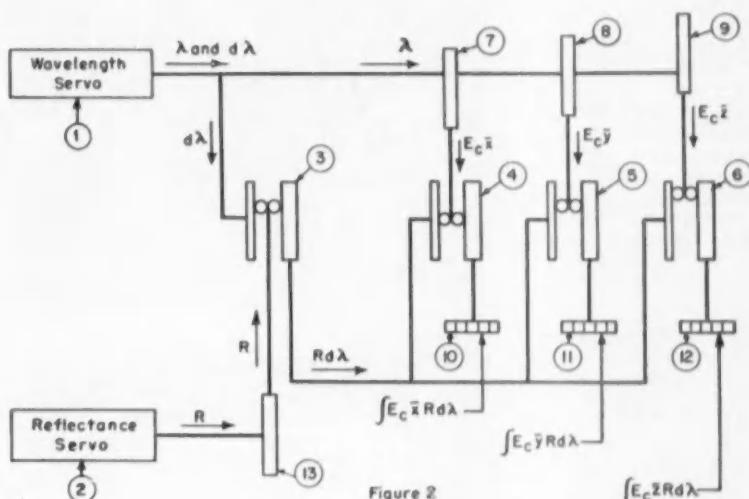


Figure 2

cording Spectrophotometer, uses the ball and disc analog integrator to perform the mathematical operations. The integrated values appear on three direct-reading counters.

### THE TRISTIMULUS INTEGRALS

The ATI evaluates the following integrals:

$$X = \int E_x R d\lambda, Y = \int E_y R d\lambda, \text{ and}$$

$$Z = \int E_z R d\lambda$$

where  $E$  represents the spectral distribution of the illumination source,  $R$  the spectral reflectance of the colored object,  $x$ ,  $y$ , and  $z$  the tristimulus values of the spectral colors,  $\lambda$  the wavelength, and  $X$ ,  $Y$ , and  $Z$  the tristimulus values of the colored object under the given illuminant.

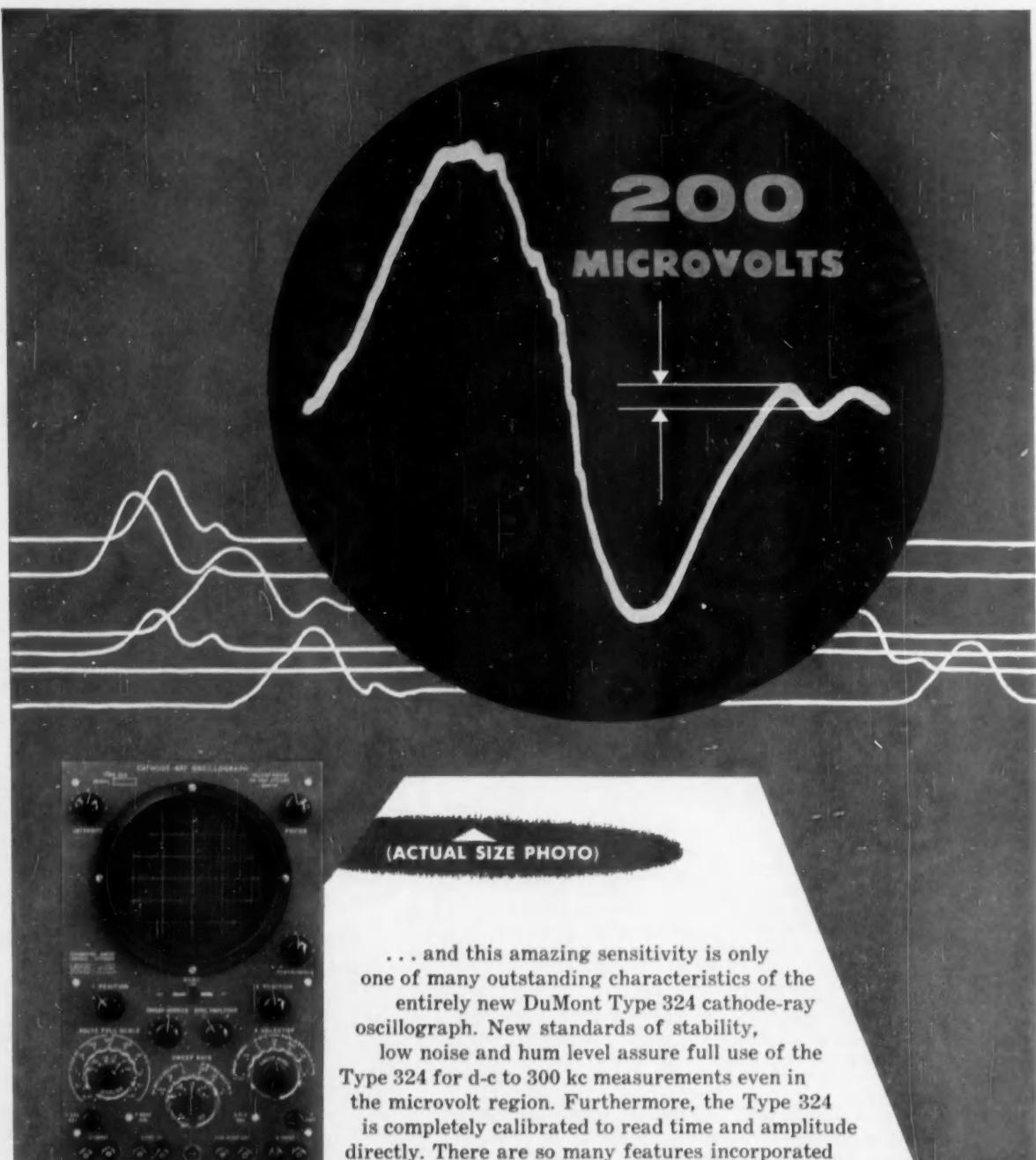
### BALL AND DISC INTEGRATOR

The basic component of the ATI

is the ball and disc integrator, shown in Figure 1. Here is how this computing element works: when the disc of the integrator rotates, it forces the two balls to rotate and they, in turn, rotate the cylinder. The angular rotation of the cylinder shaft is proportional to the product of the distance of the balls from the center of the disc and the angular rotation of the disc shaft. If the rotational displacement of the disc is  $x$  and the distance of the balls from the center of the disc is a function of  $x$ ,  $f(x)$ , then the device performs integration according to the following relationship:

$$Y = K \int_{x_1}^{x_2} f(x) dx$$

where  $K$  is a constant of proportionality dependent on the dimensions of the unit, and where the integration



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# A Diode's "Zener" Voltage Suits it for Two-speed Data Switching

R. KRAMER, Massachusetts Institute of Technology, and W. R. PORTER, Lieutenant, USN\*

\* Formerly with MIT's Servo Lab.

The silicon diode's breakdown characteristic can be used in synchro data-switching circuits. Simplicity and smooth constant-gain transition are some values gained.

FIG. 1. Typical voltage-current relationship for (A) single silicon junction diode, (B) two back-to-back.

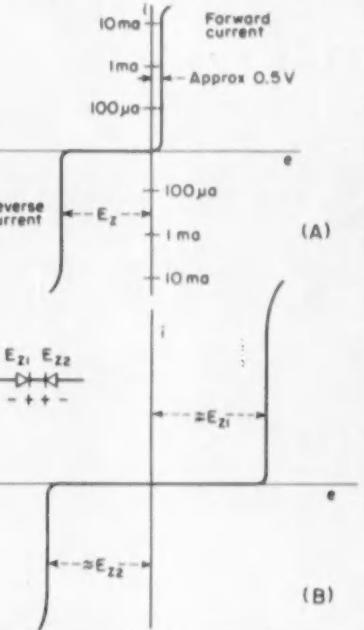
The silicon junction diode is a semi-conductor diode with very high back resistance up to a critical reverse voltage. At this critical "Zener" breakdown voltage, the back resistance drops to a very small value. The Zener voltage is very nearly constant over several decades of reverse current; and it can be controlled during manufacture. At least one manufacturer will supply silicon diodes with the Zener voltage within a small percentage of specified values. Figure 1A shows a typical voltage-current characteristic for a silicon junction diode.

Two silicon diodes in series connected back-to-back have the characteristic shown in Figure 1B. A single

diode could be used for switching if the operating point were biased to one-half  $E_z$ , but two diodes eliminate the bias problem.

Figure 2 shows the switching circuit. Two data circuits are represented typically by synchro control transformer secondaries with outputs  $e_1$  and  $e_n$  for the 1-speed and  $n$ -speed circuits. Amplitude  $B$  is the synchro maximum output in rms volts.

It is often desirable that the sensitivity at the output of the switching circuit be independent of whichever synchro is controlling. This maintains constant system gain. It may be accomplished by adjusting the gain  $A$  and the resistance voltage-divider at-



tenuation to suit the speed ratio  $n$ . For small angles the  $n$ -speed sensitivity is  $n$  times that of the 1-speed; therefore, the amplification should be

$$A = \frac{n}{1 + \frac{R_1}{R_2}} = \frac{n}{1 + a}$$

The equality applies for equal gain in the two circuits. The gain can be made greater to produce saturation-slewing into the fine-data control zone.

Where the output of the data-pick-off is a sinusoidal function of position, the voltage  $e$  across the diodes (before conduction) is

$$e = \sqrt{2} B \sin \omega t \left[ A \sin \theta - \frac{1}{1+a} \sin n\theta \right]$$

## THE SWITCHING CIRCUIT . . .

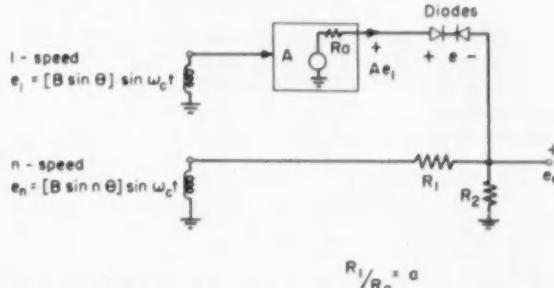


FIG. 2. Circuit for silicon diode data switch has one stage of amplification. Any other method also needs this gain; does not have this simplicity.

## . . . AND ITS PERFORMANCE

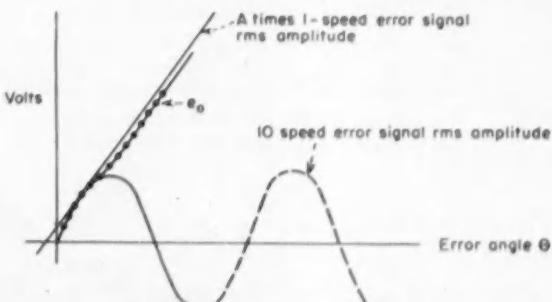


FIG. 3. Switch occurs between 50 and 70 deg on the fine-data synchro. Shown for a Zener voltage of 5 v in a 10-speed system.

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occurs between the limit  $x_1$  and  $x_2$ .

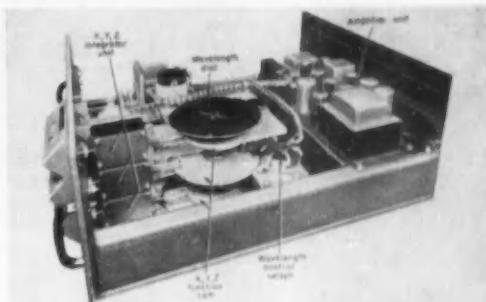
#### OPERATION OF THE ATI

The Tristimulus Integrator receives two signals from the recording spectrophotometer; these signals repeat, through two servo systems, the reflectance and wavelength values produced by the spectrophotometer. Figure 2 shows the schematic diagram of the mechanical circuit of the ATI.

Here, the first integrator unit (3) receives motion from the wavelength servo (1). The balls of this integrator are positioned by the reflectance servo (2) and a cam (13). Thus, the number of turns of the output cylinder of the integrator unit (3) is proportional to the product of the reflectance and the change in wavelength, or  $Rd\lambda$ .

The parameters  $E$ ,  $x$ ,  $y$ , and  $z$ , are all dependent on the wavelength, but for a given light source the products  $Ex$ ,  $Ey$ , and  $Ez$  appearing in the tristimulus integrals can be represented by individual cams profiled to

FIG. 3 Assembly of the Automatic Tristimulus Integrator allows easy installation and adjustment, and combines neatly with the recording spectrophotometer (not shown) for which it was designed. The important parts of the device are indicated on the photograph.



these functions. The wavelength servo positions these cams, (7), (8), and (9). The cams, in turn, position the balls on integrator units (4), (5), and (6).

$Rd\lambda$ , the output of the integrator unit (3), rotates the discs of three other integrators. The number of revolutions of the cylinders of integrator units (4), (5), and (6) must equal  $ExRd\lambda$ ,  $EyRd\lambda$ , and  $EzRd\lambda$ . These products are then totaled in the three counters (10), (11), and (12).

Thus when the wavelength of the spectrophotometer is varied from 400 to 700 millimicrons, the counters record the value of the three integrals that make up the tristimulus values:

$$X = \int_{400}^{700} ExRd\lambda;$$

$$Y = \int_{400}^{700} EyRd\lambda;$$

$$\text{and } Z = \int_{400}^{700} EzRd\lambda$$

## Measuring Small Phase Angles

JACK GILBERT, Norden Laboratories

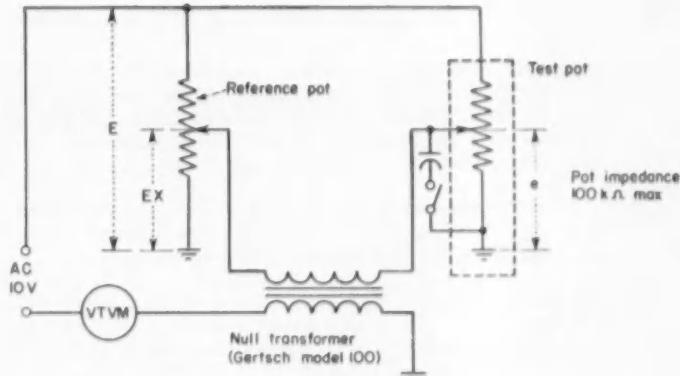


FIG. 1

plus or minus 5 per cent at midband (350—1000 cps).

The reference voltage,  $E$ , is divided by the reference pot slider until a minimum or null reading is observed on the vacuum tube voltmeter. This voltmeter reading will be the quadrature voltage. The phase shift created by the reference pot is insignificant because of its relatively low impedance and internal construction. Figure 1 illustrates the circuit and Figure 2 its theory of operation.

The voltage ratio  $X$  is read directly from the dial of the reference pot,

and the null voltage from the meter. An infinite resolution slide-wire type pot is desirable for the reference volt-

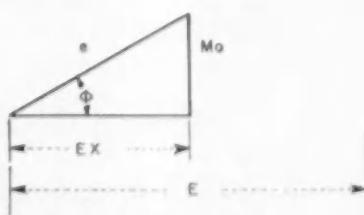
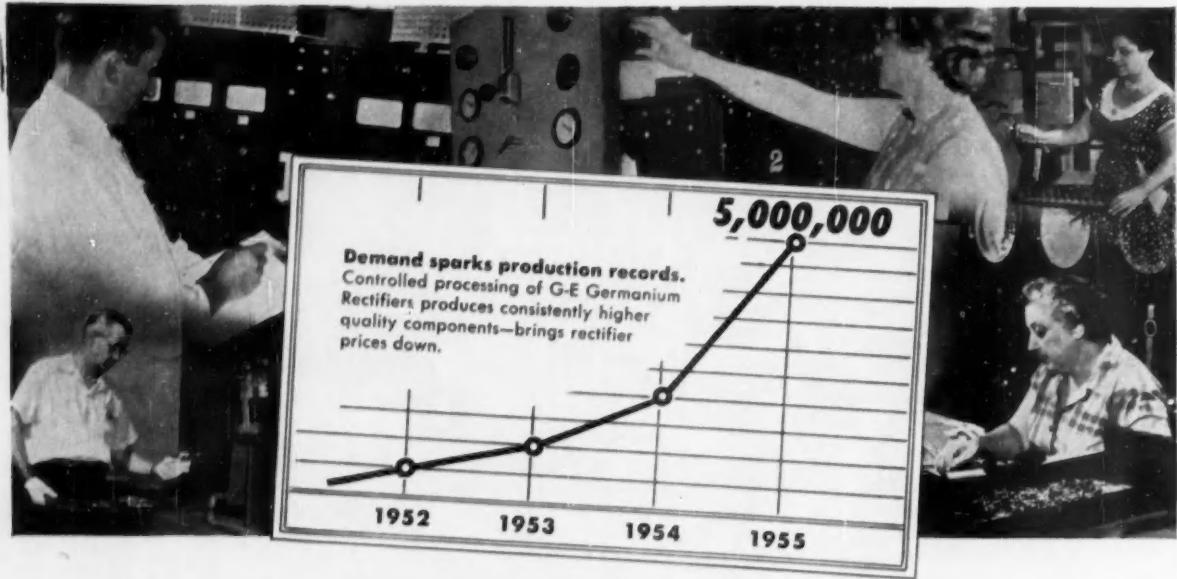


FIG. 2



## G-E Germanium Rectifier Production Breaks the 5 Million Mark

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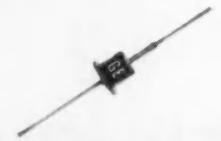
**PROVED QUALITY!** Of the 5,000,000 rectifiers produced, only a fraction of 1% have required adjustment under the terms of General Electric's full year warranty!

**Wide Range of Designs.** G-E rectifiers are available in a broad range of designs for many applications—for electronic computers, control equipment, power supply units, magnetic amplifiers; for military and industrial needs requiring custom designs; and for almost any application where DC power is required. G-E Germanium Rectifiers are more compact, and weigh less—as much as 75% less than comparable rectifiers of other types—and meet the rigid requirements for performance established by the U. S. Navy, Air Force, and Signal Corps. What's more, G-E Germanium Rectifiers are *warranted for one full year*.

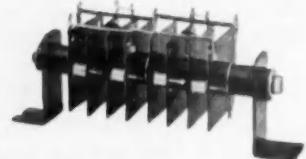
**Immediate Delivery.** Mass production assures fast delivery on all G-E Germanium Rectifiers regardless of quantity. For complete information concerning your rectifier needs, contact your G-E Semiconductor Representative. Or, write: *General Electric Company, Semiconductor Products, Section X9916, Electronics Park, Syracuse, New York.*

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**Diffused Junction Germanium Rectifiers** combine very high forward conductance with very high back resistance. The high temperature and magnetic amplifier rectifiers feature very low reverse current ratings at ambient temperatures of 85°C.



**Power of the basic rectifier unit** is boosted 5 times by adding a copper fin. Stacked one to twelve fins in series or parallel, the rectifier may be operated as half wave, full wave, or bridge circuits, and many other types of single or polyphase circuits. Typical power ratings are as high as 3 amps @ 190 volts; 1.5 amps @ 575 volts; 3.6 amps @ 140 volts, etc.



**The Medium Power Rectifier** has a 5 amp rating at 200 volts (55°C). At 85°C it is rated 2.5 amps at 100 volts. These rectifiers, stacked in series or parallel, have ratings in thousands of watts depending on the design of the circuit.

age divider. The phase shift is an angle whose tangent is equal to  $Mo/EX$ . For angles less than 6 deg, multiply the ratio  $Mo/EX$  by 57.3 deg to calculate a phase angle within the accuracy of the measurement technique. If a constant reference source is used, the dial of the voltmeter can be calibrated in phase shift directly.

It will be noted that as the phase angle becomes smaller, variations in  $EX$  produce an increasingly greater role in the variations of  $Mo$ . Hence, the accuracy of the technique for small angles is exceeded by its sensitivity. To achieve the indicated accuracy of 5 per cent, the reference pot should be accurate to  $\frac{1}{2}$  per cent for angles less than 1 deg and the meter calibrated within 3 per cent.

For potentiometers, a small capacitor may be switched across the test component to determine the polarity (lead or lag) of the shift. The change in meter reading is then indicative of the polarity of the phase angle. For instance, if the shift is caused by capacitive reactance of the tested part, the condenser will augment them, increasing the negative phase shift and hence the null voltage. Similar techniques may be used for other components.

A plot of the phase shift of an unloaded ten-turn potentiometer can be

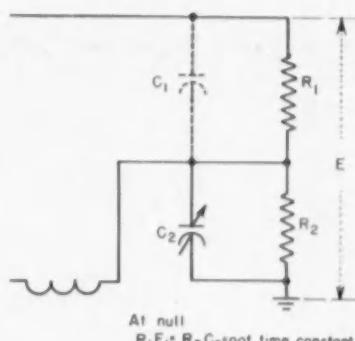


FIG. 3.

easily calculated once its time constant is known. The time constant could be found by suitable calculation involving the phase shift measurements (obtainable by the balancing technique), but here is a direct way of finding it.

Figure 3 shows the setup.  $R$  is the entire ten-turn pot.  $R, C$  is the time constant produced by the distributed capacity of the pot.  $C_2$  is a variable capacitor, and  $R_2$  a small fixed resistor of approximately the same resistance as the pot. The phase shift through this resistor is too small to be significant. Only when the adjustable capacitor,  $C_2$ , is such that  $R_2C_2$  equals  $R, C$ , is the output voltage in phase with the

input voltage. With the reference pot set near its halfway point, the in-phase component of the voltage  $e$  will equal the voltage  $EX$ , but will be out of phase with  $EX$  depending on the time constant of  $R, C$ .

This time constant can now be used in the following equation to find the quadrature voltage of any of the ten-turn pot's shaft settings.

$$Mo = E \omega RC (1 - 2S) (1 - S) (8)$$

$E$  = input voltage

$\omega$  = radian frequency

$R$  = potentiometer overall resistance

$C$  = equivalent lumped capacity measured across end terminals

$S$  = shaft position, in per cent of maximum rotation.

Similarly, one can calculate phase shift (in radians) by

$$\phi = \omega RC (1 - 2S) (1 - S)$$

Since similar expressions can be derived for other pot types, one reading provides all the information needed to plot a pot's phase shift characteristics.

Rather than a slide-wire pot, an ideal standard voltage divider is a Gertsch Ratio Standard, Model PT-5. Resolution better than 0.001 per cent is available together with a voltage ratio accurate to within 0.004 per cent. The advantage of this item is accurate output with very low internal impedance and extremely low phase shift.

## Magnetics Sleuth a Hidden Valve

EDWARD S. SHEPARD, SR., AiResearch Mfg. Co.

The problem at AiResearch was to monitor the angular position of a butterfly valve, which operated inside a round aluminum duct. Engineers solved the problem by magnetizing the valve and following its movement with a magnetic compass, directly under it on the outside of the duct. Here's the way they did it:

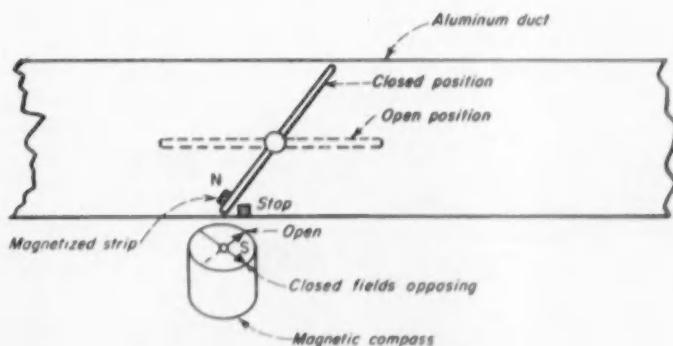
The butterfly valve, a simple air-operated damper, did its job under rather high air velocity and air pressure. Two stipulations concerning the monitoring method were that no holes were to be made in the damper, and nothing was to be attached to it that could not be removed after the tests were completed. Only one method seemed possible under these conditions and it turned out to be the simplest.

A tiny magnetic strip (it could have been a pellet as well) was fastened to an edge of the valve by strain-gage cement. The resulting increase

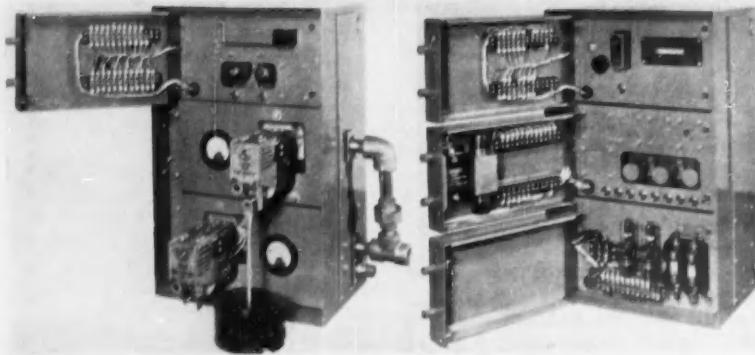
in the thickness of the valve at that point, less than  $\frac{1}{8}$  in., represented negligible air resistance.

The magnetic compass mounted on the outside of the duct was a fluid-damped device of high quality. In the illustration, the valve is in the

closed position and the compass is oriented so that its deflection is at a maximum. As the valve is moved from the closed position the compass needle will follow through a 90 deg excursion, at the end of which the valve will be fully open.



## NEW PRODUCTS



### ALL ELECTRONIC tubeless circuit for high speed, multi-variable flow computer.

Accepted method of measuring gas flow in large quantities involves the measurement of a differential pressure across an orifice plate. However, the differential pressure itself is not a direct or accurate indicator of flow. Involved in the accurate measurement of flow by differential pressure is the absolute static pressure, the temperature base, the specific gravity, the flowing temperature, the Reynolds number, the expansion factor, and the super-compressibility. Some of these factors vary rapidly, some slowly, some remain constant in given installations.

A variety of pneumatic, mechanical, and manually operated devices have been designed to more or less automatically make the required computation. Now comes the electronic method, represented by the ingenious device depicted by the block diagram. With the advent of accurate pressure-to-voltage transducers, it has become possible to develop such electronic flow calculators, and one of their advantages, the maker of the present device says, is the possibility that electrical outputs without computation lags can be used as control voltages. Other advantages: the ability to indicate and record with conventional electrical instruments, and the possibility of high frequency response within the computer. The latter enables exact computation during rapid fluctuations of the measured pressure.

The importance of this last feature, it is said, becomes apparent when one realizes that the basic equation for the computation of flow involves the square root of the differential pressure. Hence, the flow that might occur for the steady average value of a

fluctuating pressure signal is not equal to the flow that might occur during fluctuations around this figure. An instrument incapable of following these fluctuations would tend to present the average value for flow computation, which, as mentioned, differs from the flow resulting from the fluctuating pressure itself.

Since the ideal location for many flow meters is immediately after a pump, the magnitude of the pulsations in a gas line can be quite substantial. Also, flow fluctuations can be increased due to phasic effects of various pulsations in a given system.

The flow computer shown above is free of vacuum tubes and yet completely electronic. Its design, says the maker, was made possible only since the advent of pressure-to-voltage trans-

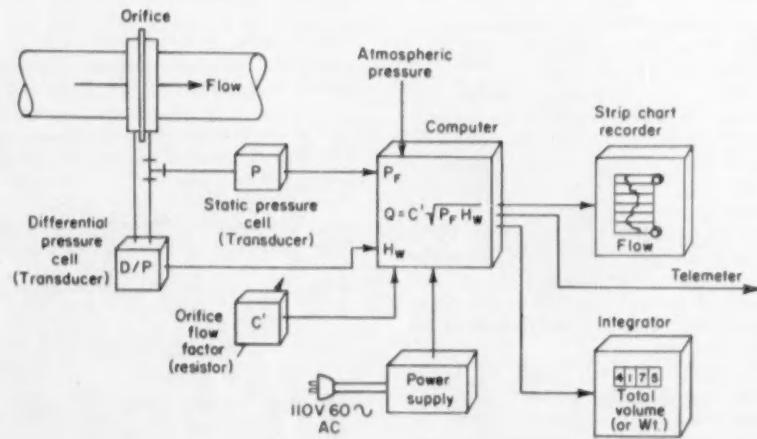
### LISTING IN GROUPS

- 1-2 Two Flow Computers
- 3-12 Some Sensors
- 13-25 Indicators & Testers
- 26-30 Control Valves
- 31-36 Pulse Products
- 37-41 Relays & Switches
- 42-46 Rotary Actuators
- 47-50 Power Sources
- 51-60 Assorted Hardware

ducers, high gain magnetic amplifier computing circuits, and reliable semiconductors, all just recently available. The resulting system is said to perform with an accuracy at the output of 1 per cent. The actual computing portion of the system operates with an accuracy of 0.01 per cent, but the indicating devices are unable to match this tolerance. Flow fluctuations as high as 500 cycles per minute are followed by the system.

An advantage of the completely electronic design, the maker adds, is the relative ease of introducing various independent variables into the computation from conventional electrical pickups. Southwestern Industrial Electronics Co., Houston, Tex.

Circle No. 1 on reply card



**MECHANICAL flow computer  
integrates product of square  
roots.**

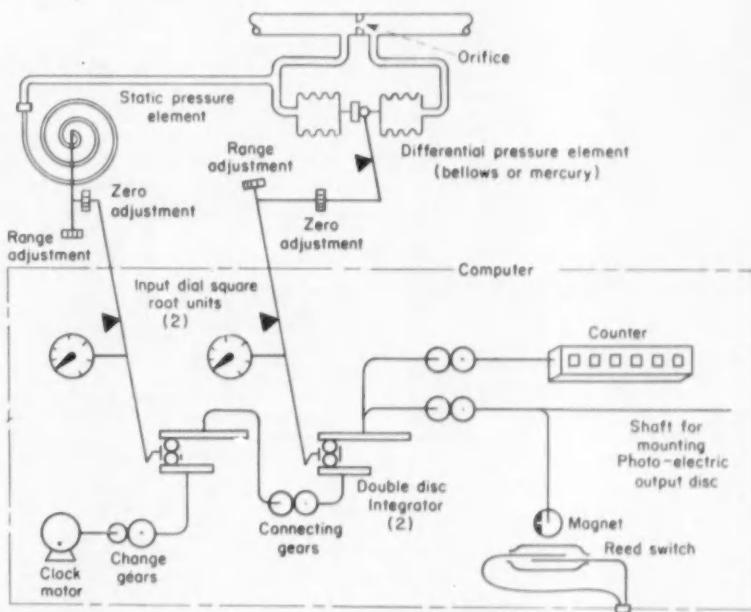
In describing the flow computer on the opposite page, some mention was made of the basic problem involved in measuring flow from a differential pressure indication. Where the object of a flow measurement is the integration of its rate for the purpose of indicating the total volume of material transmitted, the instrument shown here does the job through an ingenious mechanism in a compact package.

A pneumatically or electrically driven clock motor provides the basic power source for the flow integrator, continuously computes the extension factor in the flow equation; that is, the square root of the product of static and differential pressure. The result is shown on a counter-like display.

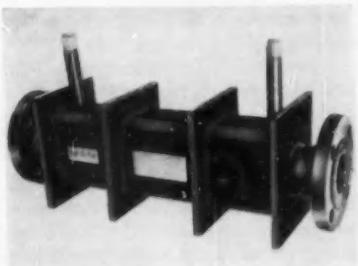
The figure at the lower left shows how conventional pressure element inputs are used to control the operation of two unique square root deriving double-ball-and-disc type integrators connected in series. They place an extremely small load on the pressure elements. The integrators are used here as speed changers, multiplying the output of the clock motor by the square root of static pressure and the square root of the differential pressure. This produces the required function. A dial indication of the static and differential pressures utilizes square root calibration to provide a direct reading of these values from the sensing bellows.

A standard electric clock motor provides enough torque to total 18,000 counts per hour. An optional feature is a magnet-operated reed switch, which can provide a pulse rate output to operate a remote electro-mechanical counter. Librascope, Inc., 808 Western Ave., Glendale, Calif.

**Circle No. 2 on reply card**



## SENSORS AND DETECTORS



**GAS LOW creates linear  
differential pressure.**

This gas flow measuring device (left) indicates flow linearly when used with differential pressure pickups. It operates on the principle of the linear pressure drop set up by the viscous flow of fluids in thin channels. It accomplishes this effect by providing a number of flow channels in which the Reynolds number is kept below 400 at full scale flow. Pressure taps permit manometer or differential pressure gage sensing. The linearity of the element assures true average flow indica-

tion despite pulsating flow input. Further advantages are low pressure drop, accuracy down to zero flow, and reliability of a static element. Standard flow ranges are from 0.003 cfm to 100 cfm for steam and most of the common gases, at pressures from 1 in. Hg absolute to 2,000 psig. National Instrument Laboratories, Inc., 6108 Rhode Island Ave., Riverdale, Md.

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Avion's flexibility and ingenuity, coupled with extensive experience in Electronics, Mechanics and Optics can better serve you.

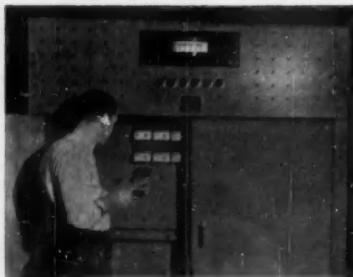
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## NEW PRODUCTS



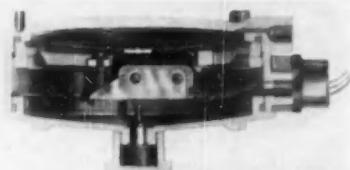
### SEVENTY-TWO points scanned and controlled.

Up to 72 temperature-sensed stations are scanned and controlled within 4 minutes by this new Control Center. Thermistors are used as sensing elements and the control units provide dual SPDT switch action with a spread between setting indexes from 0 to 10 per cent of the entire scale. Push button selection of any one of the monitored points is possible, with visual and audible alarm for "off limits" conditions. Wheelco Instruments Div., Barber-Colman Co., Rockford, Ill.

Circle No. 4 on reply card

**VIBRATION MONITOR:** A new, explosion-proof device operates on the theory that with rotating equipment an increase in vibration bodes ill. It closes circuits carrying up to 5 amp to signal the fact. The Beta Corp., Forest Ave., at Ridge Road, Richmond 26, Va.

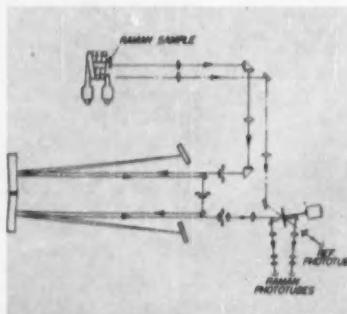
Circle No. 6 on reply card



### HALF-INCH WATER pressure change operates switch.

This externally adjusted switch reacts when a liquid or gas pressure rises or falls to a value of 0.5 in. of water. It requires air or inert gas as its reference pressure. The setpoint can vary from 0 to 45 in. of water. Barksdale Valves, 5125 Alcoa Ave., Los Angeles 58, Calif.

Circle No. 7 on reply card



### RAMAN spectrophotometer shows tiny samples.

The impressive optical system above is the heart of a new Raman Spectrophotometer, Cary Model 81, described as particularly useful for small samples and quick analysis. With the Model 81 a complete Raman spectrum of benzene can be made in 5 min with as little as 0.1 milliliters of sample. Because water and other polar compounds exhibit weak Raman spectra, they are suitable for use as solvents in Raman spectroscopy. Applied Physics Corp., 362 W. Colorado St., Pasadena 1, Calif.

Circle No. 5 on reply card

**EXTENDED RANGE FLOWMETER:** A flowmeter intended for engine test applications, hydraulic test work, and as a flow standard for calibrating flow metering equipment features automatic correction for changes in density of the metered fluid through variations of specific gravity from 0.6 to 0.9.

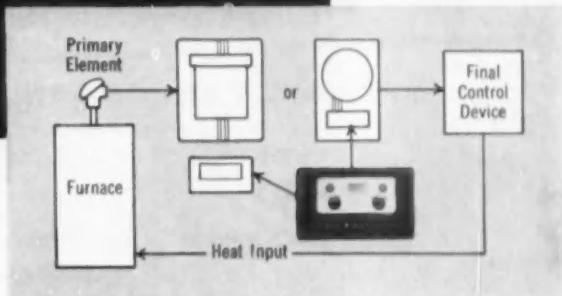
The specific gravity sensing element consists of a precision potentiometer rotated by the fluid flow. Its voltage output influences the ac to dc converter used with the ac output flow sensor. The device is accurate to within  $\frac{1}{2}$  per cent full scale. By automatically switching to new flow sensing elements as flow demands require, five ranges are provided for a full flow range of 30,000 to 1 or more. Potter Aeronautical Co., Route #22, Union, N. J.

Circle No. 8 on reply card

**HIGH TEMP COUPLE:** For use in temperature up to 1800 deg C is a new thermocouple that features platinum 30 per cent rhodium to platinum 6 per cent rhodium calibration. It achieves its high-range performance without sacrificing either corrosion re-



*This control relay is the heart of the new Series 60 electric proportioning control system . . . which also includes a Speedomax® indicator/recorder, a primary element and a final control device.*



### WITH THIS NEW SERIES 60 CONTROL

# You can push your furnace HARDER

■ If you're wasting valuable furnace time bringing a batch to temperature . . . slowing down heating rate to prevent overshoot . . . Series 60's adjustable rate of approach will bring furnace to control point smoothly—safely—in shortest possible time.

If you're losing production on your *continuous* processes due to hot spots . . . slow start-ups . . . poor combustion, Series 60's sensitivity, speed of response and control actions will provide fast, uniform heat distribution within the furnace . . . head off temperature departures as soon as they start.

Regardless of your process, if your furnace, your product and your production isn't benefiting fully from your present controls, it'll pay you to look into Series 60.

**COMPLETE, FLEXIBLE SYSTEM** Heart of this flexible system is L&N's new, compact Series 60 electronic proportioning control relay which receives information from the Speedomax indicator/recorder . . . immediately amplifies it and adjusts the final control device to hold temperature in line. This control relay is only 6" x 11" x 11"—about half the size of the Series 50 unit which it replaces. It's an integral part of our new Speedomax H instruments . . . mounts in its own case when used with Speedomax G. Expendable components—tubes, electrolytic capacitors, etc.—are plug-in for fast servicing.

**VARIETY OF CONTROL ACTIONS** Series 60 is

available for Position-Adjusting Type (P.A.T.) or Duration-Adjusting Type (D.A.T.) control.

P.A.T. regulates input by adjusting the position of a valve; D.A.T. provides a two-position operation of the final control device . . . regulates input by adjusting the durations of heat-on time of a contactor, or of full-open time of a valve.

P.A.T. is supplied for single-action (proportional) or 3-action (proportional, reset and rate) control . . . D.A.T. for two-action (proportional and reset) or 3-action control. Proportional regulates input according to size . . . reset according to duration . . . and rate according to speed of temperature change. Choice of type depends upon your product, your process and your production.

In the 3-action units, reset and rate operate independently—permit optimum settings for best possible control. Reset is adjustable from 0-100 repeats/min; first step above zero is .01. Rate time is continuously adjustable from 0-8 minutes.

For a full description of Series 60 control, contact your nearest L&N office, or write 4918 Stenton Avenue, Philadelphia 44, Penna.

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## SANBORN

OSCILLOGRAPHIC RECORDING SYSTEMS

### "ON THE JOB"

PROVIDE VALUABLE  
DYNAMIC ANALYSIS DATA

#### PRODUCTION TESTING

of components is accomplished by a Servo Component manufacturer by means of a Sanborn Single-Channel Recording System with a Sanborn Servo Monitor Preamplifier.



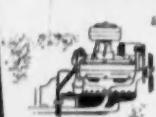
#### DYNAMIC PERFORMANCE



of valves when equipped with a certain pneumatic Valve Positioner is determined by the manufacturer with a Sanborn Two-Channel System and Sanborn Carrier Amplifiers.



#### ACCELERATION and TORQUE



are recorded simultaneously by an oil company in their study of fuels and lubricants as they relate to engine performance.



#### DRONE MISSILE

manufacturer can simulate the flight of the missile and derive information concerning its behavior under certain conditions by means of an analog computer and a Sanborn Four-Channel System with four Sanborn AC-DC Preamplifiers.



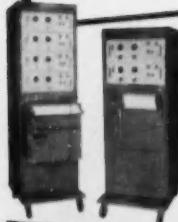
#### ATOMIC REACTOR



to be used for power generation in prototype plant is studied with the help of a Sanborn Eight-Channel System which records the output of thermocouples, strain gage pressure pickups, and resistance devices.

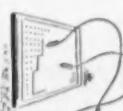


#### ANALOG COMPUTING



center uses Sanborn Eight-Channel Systems to record the solutions of problems having six or eight variables.

Sanborn systems specially designed for this type of work utilize Dual-Channel DC Amplifiers.



#### Sanborn 150 Features Include:

Inkless Recording in True Rectangular Coordinates  
Preamplifier Interchangeability  
Eleven Types of Preamplifiers  
Improved Over-all Linearity  
Accessibility of Chart During Recording

#### INDUSTRIAL DIVISION

**SANBORN  
COMPANY**  
CAMBRIDGE 39, MASSACHUSETTS

## NEW PRODUCTS

sistance or sensitivity. Thermo Electric Co., Inc., Saddle River Township, Rochelle Park P. O., N. J.

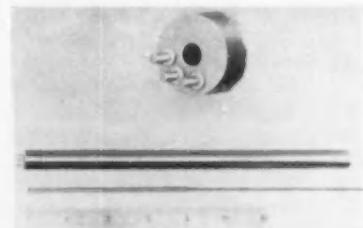
Circle No. 9 on reply card



#### MOTION TRANSDUCER sensitive to a millionth of an inch.

Motions as little as one millionth of an inch to as large as 0.124 in. are detected by the Model 100 Universal Displacement Transmitter. A micrometer zero adjust permits mechanical and electrical zero to be adjusted after installation. Sensitivity is 5 millivolts per 0.001 in. with 6.3 v, 60 cps ac excitation. Output impedance is 200 ohms, linearity to  $\frac{1}{2}$  per cent. Dyatronic Corp., 216 S. Main St., Dayton 2, Ohio

Circle No. 10 on reply card



#### POSITION PICKUP insensitive to high temperatures.

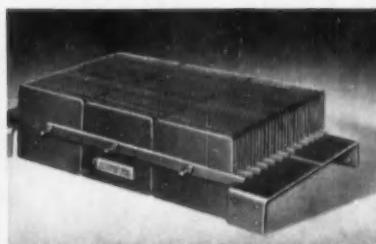
This linear motion transducer operates on the principle of variable permeance as part of an ac bridge. It mounts in a  $\frac{1}{2}$  in. hole and withstands temperatures as high as 1,300 deg F.

# International Rectifier

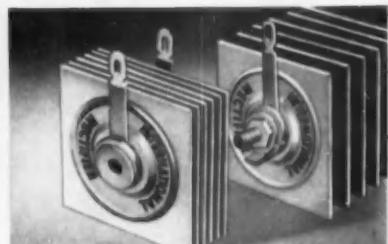
## Selenium and Germanium Rectifiers

### International Selenium Products

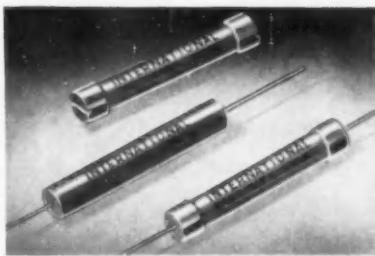
Pressed powder or vacuum process used as determined by our Applications Engineering Dept. The most widely used Industrial Power Rectifiers in Industry today!



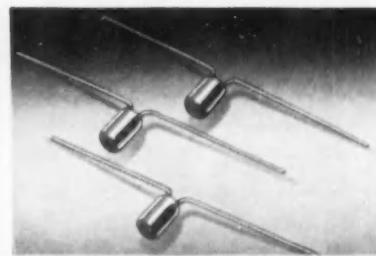
INDUSTRIAL POWER RECTIFIERS



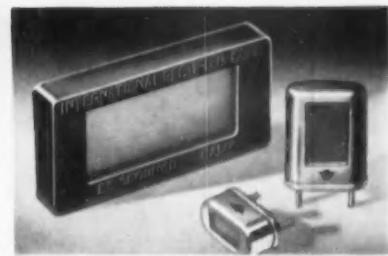
TV AND RADIO RECTIFIERS



HIGH VOLTAGE CARTRIDGE RECTIFIERS



SUB-MINIATURE SELENIUM DIODES



PHOTOELECTRIC CELLS

Designed for long life and reliability in Half-Wave, Voltage Doubler, Bridge, Center-Tap Circuits, and 3-Phase Circuit Types. Phenolic Cartridge and Hermetically Sealed types available. Operating temperature range:  $-65^{\circ}\text{C}$  to  $+100^{\circ}\text{C}$ . Specify Bulletin H-2

Developed for use in limited space at ambient temperatures ranging from  $-50^{\circ}\text{C}$  to  $+100^{\circ}\text{C}$ . Encapsulated to resist adverse environmental conditions. Output voltages from 20 to 160 volts; output currents of 100 microamperes to 11 MA. Bulletin SD-1B

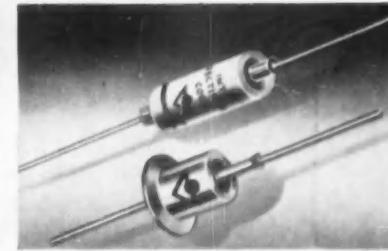
Self-generating photocells available in standard or custom sizes, mounted or unmounted. Optimum load resistance range: 10 to 10,000 ohms. Output from .2 MA to 60 MA in ave. sunlight. Ambient temperature range:  $-65^{\circ}\text{C}$  to  $+100^{\circ}\text{C}$ . Bulletin PC 649

### International Germanium Products

High quality units of improved design are the results of years of experience in the production of exceptionally fine germanium crystals plus extensive research, development and field performance testing!



GERMANIUM POWER RECTIFIERS



GERMANIUM DIODES

This new line features: High efficiency—up to 97%, Lowest forward drop, High reverse to forward current ratio, unlimited life expectancy. No reforming required after storage. Ratings: 26 to 66 AC input v. per junction: 150 to 100,000 amps DC output. Operating temperature range:  $-55^{\circ}\text{C}$  to  $+75^{\circ}\text{C}$ . In three styles. Bulletin GPR-1

**POINT CONTACT.** High quality crystals—long reliable life—superior resistance to humidity, shock, temp.-cycling. Bulletin GD-2  
**JUNCTION POWER.** Hermetically sealed—welded construction. Available in Standard JETEC 1N91, 1N92, 1N93 types. For diodes to meet your specific requirements, consult our Semiconductor Division.

a world of difference through research!



For bulletins on products described **WRITE ON YOUR LETTERHEAD**  
to our **PRODUCT INFORMATION DEPARTMENT**

# International Rectifier

C O R P O R A T I O N

EXECUTIVE OFFICES: 1521 E. GRAND AVE., EL SEGUNDO, CALIFORNIA • PHONE OREGON 8-6281

WORLD'S LARGEST SUPPLIER OF INDUSTRIAL METALLIC RECTIFIERS

# Magnetic Amplifiers • INC

AFFILIATE OF  
GENERAL CERAMICS  
CORPORATION

—announces its new

## VARIABLE SPEED DRIVE

# MAGNE-SPEED\*



Stepless, instant starting, compact, 50:1 speed range, good regulation without tachometer, long life, virtually maintenance free service, low cost, fast response, reversibility, dynamic brake, local or remote control. Write for Bulletin S580-5-55.

Other  Products and Services

**Magnetic Servo Amplifiers**

**Transi-Mag \* Amplifiers**

**Analog Computers**

**Photoelectric Controls**

**DC and AC Regulated Power Supplies**

Application engineering and conversion of tool machines and production processes to automatic control.

\* Trade  
Name

**Magnetic Amplifiers • Inc**

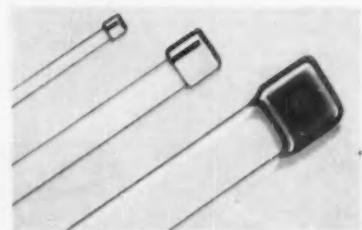
Tel. CYPRESS 2-6610 • 632 TINTON AVE., NEW YORK 55, N. Y.



## NEW PRODUCTS

The body exposes only stainless steel and is designed for use in furnaces, reactors, etc., where it will measure motion up to 4 in. and down to 0.2 in. Resolution of better than 0.000,000,1 in. and linearity from 1.5 to 0.3 per cent are claimed for all models. Operating sensitivities are from 0.1 to 3 v per in. Crescent Engineering & Research Co., 11632 McBean St., El Monte, Calif.

Circle No. 11 on reply card

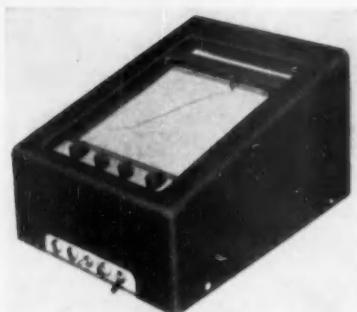


**WAFFER-LIKE thermistors**  
available without delay.

Seen above are a few examples of a complete new line of wafer-sized thermistors. The new elements are stocked in resistances ranging from ohms to megohms, and with temperatures coefficients as high as 7 per cent per deg C. The maker says the sample quantities in any resistance value are available without delay. Gulton Industries, Inc., Metuchen, N. J.

Circle No. 12 on reply card

## INDICATORS AND TESTERS

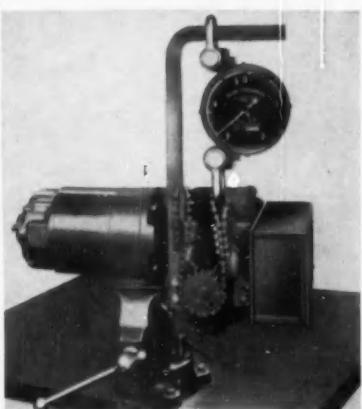


**FLAT BED PLOTTER** features high speed response.

The X-Y recorder shown above uses 8½-by-11-in. chart paper for flat bed presentation. Full scale pen speed is  $\frac{1}{2}$  sec. Eleven scale ranges run from

5 millivolts to 500 v full scale. Input impedance is 200,000 ohms per volt. Electro Instruments, Inc., 3794 Rosecrans, San Diego 10, Calif.

Circle No. 13 on reply card



**SIMPLE RIG** for measuring static torque of motors.

These Dillon people are loaded with interesting applications for their dynamometer. The photo above shows how you can measure the static torque of a motor with a minimum of bother. W. C. Dillon & Co., Inc., 14620 Keswick St., Van Nuys, Calif.

Circle No. 14 on reply card



**VACUUM-TUBE voltmeter** measures pulse height.

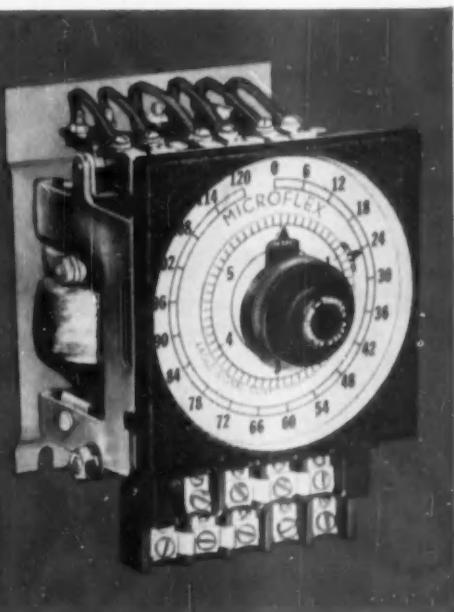
The instrument above has the unique function of measuring the amplitude of pulses regardless of their widths. Accuracy is to within 2 per cent full scale and readings are independent of widths of from 0.01 microsec upward. Ranges of 0 to 10, 30, and 100 v are offered. The PV-812 Pulse Height Vacuum-Tube Voltmeter is provided with a 5-in. meter and knife-edge point and mirror scale. Television Accessories Co., 1412 Great Northern Bldg., Chicago 4, Ill.

Circle No. 15 on reply card

# EAGLE

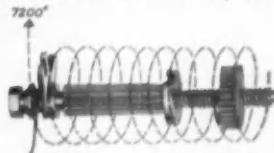
## Microflex Reset Timer

FOR  
MACHINE  
AND PROCESS  
CONTROL



### Insures "20-to-1 ratio" accuracy

Time settings of pinpoint accuracy are a reality, thanks to the Microflex double dial. It takes one complete turn of the *inner* dial to advance the *outer* dial just one division. That's a 20-to-1 ratio, made possible by the patented Microflex threaded axle and pinion (see sketch). Examples of resultant accuracies are  $\pm 1/60$  of a second on a 20-second dial, and  $\pm 1/10$  of a second on a 120-second dial.



The Microflex Reset Timer is driven by a heavy-duty industrial synchronous motor. Contacts are tripped closed or open after a preset time interval. Starting and resetting are electrically controlled. Microflex offers over 150 timer operating combinations, plus a wide range of long or short time periods. It's ideal for applications like molding presses, dielectric heating, automatic mixing, die casting machines, machine tools and rubber curing.

Write for free Automation Booklet and Bulletin 110.

#### MAIL COUPON TODAY

|  |            |
|--|------------|
| <b>EAGLE TIMERS SAVE TIME . . . SAVE MONEY</b>   |            |
|  |            |
| <b>EAGLE</b><br><b>SIGNAL CORPORATION</b><br>Industrial Timers Division<br>MOLINE, ILLINOIS              |            |
| Please send free Automation Booklet and Bulletin 110 containing complete data on Microflex Reset Timers. |            |
| NAME AND TITLE _____   |            |
| COMPANY _____  |            |
| ADDRESS _____  |            |
| CITY _____   | ZONE _____ |
| STATE _____  |            |

# NEW!

1/2-inch  
wire-wound

ACTUAL SIZE

UP TO 100 K

## PRECISION POTENTIOMETERS

Now You CAN specify a Waters pot for your miniaturized designs that require 50K and 100K potentiometers. In the reliability-proved construction of the AP-1/2, these new, higher values give you:

- Resistances — 10 ohms to 100 kilohms
- Ganging — up to four units
- Three mounting styles — plain-bushing, split-bushing, or servo
- Three terminal styles — radial, axial, or wire-lead
- Automation models — for printed circuits
- Encapsulated designs available

**General specifications:** Centerless-ground, stainless-steel shaft can be sealed with O-ring; gold-plated, fork-type terminals; 2% standard linearity for 50K and 100K — 5% for lower values; temperature range —55 to +105°C, to 125°C on order; 2 watts at 80°C; anodized aluminum body 1/2" diameter × 1/2" long — 5/8" long for 100K; corrosion-resistant-alloy bushing; all electrical connections spot-welded or soldered; can be furnished with stops or for continuous rotation.

Write for your copy of our new data sheet giving useful information on these compact, dependable potentiometers.

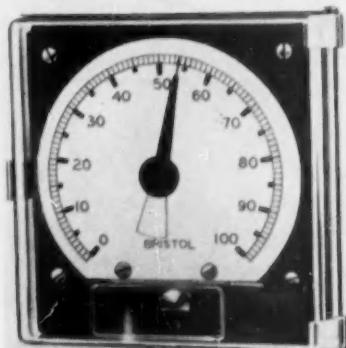


WATERS MANUFACTURING, Inc.

Waltham 54, Massachusetts

APPLICATION ENGINEERING OFFICES IN PRINCIPAL CITIES

## NEW PRODUCTS



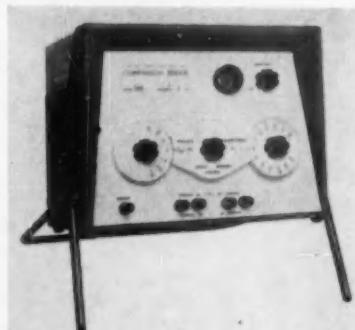
TELEMETER receiver designed for panel mounting.

The indicator above, identical in appearance to the company's line of pneumatic signal indicators, uses the pulse-width information signals of Bristol's Metameter telemetering system. Strip-chart recorders as well as dial indicators come in the 5-in. sq size. *The Bristol Co., Waterbury 20, Conn.*

Circle No. 16 on reply card

**ELECTRONIC BALANCING MACHINE:** A machine identified as Type 1250 dynamically balances high speed rotating elements at speeds up to 2,700 rpm by detecting out-of-balance masses as low as 0.0013 per cent. A stroboscopic light is controlled to locate the unbalancing mass. *Hickok Electrical Instrument Co., 10589 Dupont Ave., Cleveland 8, Ohio.*

Circle No. 17 on reply card



A COMPARISON BRIDGE for phase shift, reactance.

Here's styling for you, wrought iron and all. It's a comparison bridge for measuring the reactance, impedance, and phase shift caused by resistive, and capacitive components. Accuracy to within 0.01 per cent is



# NIXIE

## Newest STAR IN THE ELECTRONIC GALAXY

### SOME TYPICAL

### NIXIE APPLICATIONS

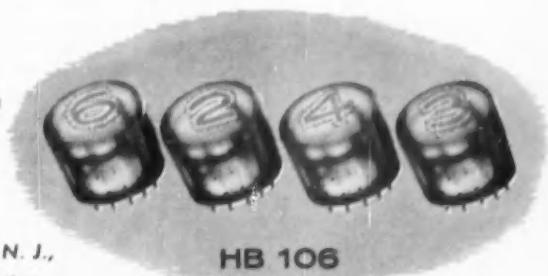
1. DIGITAL VOLTMETERS
2. COUNTERS
3. CALCULATORS
4. ALTIMETERS
5. RADAR
6. DIAL SYSTEMS
7. REMOTE POSITION INDICATORS

Haydu's 10 digit in-line numerical indicator!

Small, electronic indicating tube uses the direct read-out method which clearly displays the digits at top surface of tube. This method assures the highest readability from a wide angle . . . speeds work, reduces errors, cuts costs in hundreds of diversified applications.

### NOTE THESE OUTSTANDING ADVANTAGES:

- Small, simple plug-in tube
- Uses standard sockets
- Vivid numbers for highest visibility
- Low power required
- Operates directly off Beam Switching Tubes or any voltage source
- Radical Simplification of circuitry
- Long life
- Rugged construction



HB 106

Write to Haydu Tube Division, Dept. 10, Plainfield, N. J.,  
for complete information on your applications.



# HAYDU

BROTHERS OF NEW JERSEY  
PLAINFIELD, NEW JERSEY  
SUBSIDIARY OF BURROUGHS CORPORATION

*Engineered for  
tomorrow's needs...today...*



**NORDEN-KETAY OFFERS YOU DIRECT  
ANALOG-TO-DIGITAL CONVERSION  
WITHOUT TRANSFORMATION**

Combining accuracy with compact design, Norden-Ketay's ADC-1A family of Analog-To-Digital Converters provides you with *unambiguous natural binary output*. All digits are available nearly simultaneously...allowing a high reading rate and may be read while the shaft is in motion. Both the binary number and its complement are available, simultaneously.

**RAPID READOUT**—up to 10<sup>6</sup> per second.

**PARALLEL READOUT**—greatly simplifies external circuitry.  
**COMPACT DESIGN**—engineered for minimum size and weight.

**INPUT**—DC or pulse voltages.

**LOW TORQUE**—less than 0.2 inch ounces to turn input shaft.  
**LOW INERTIA**—approximately 9 gram centimeters<sup>2</sup>.

**CLOCKWISE OR COUNTER CLOCKWISE OPERATION**—either is possible by selection of appropriate output leads.

**AVAILABLE IN ANY CAPACITY TO 19 DIGITS**—other capacities available on special order.

For full details write for File #121.

**NORDEN-KETAY CORPORATION**

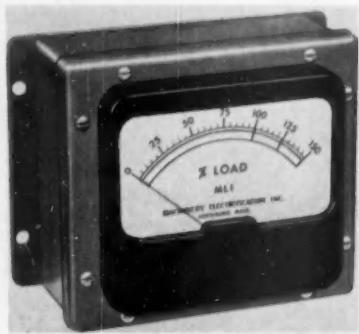
INSTRUMENT AND SYSTEMS DIVISION  
Wiley Street, Milford, Connecticut

INDICATING PRECISION PRESSURE GAUGES • REMOTE INDICATING DEVICES • ANALOG DIGITAL CONVERTERS • FORCE BALANCE  
PRESSURE TRANSDUCERS • ELECTROMECHANICAL CONTROL SYSTEMS • AIRBORNE RADAR • SHIPBOARD LINE CONTROL EQUIPMENT  
AIRCRAFT FUEL FLOW INSTRUMENTATION • ACCELEROMETERS

**NEW PRODUCTS**

claimed. The resistance range goes to 20 megohms. It contains a two-stage detector and an oscillator, enabling operation between 100 cycles and 10 kilocycles with suitable plug-in networks. Null indications are provided by an electronic eye. Electro-Measurements, Inc., 4312 S. E. Stark St., Portland 15, Ore.

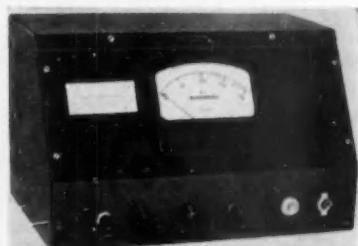
Circle No. 18 on reply card



**MOTOR LOAD** directly shown as per cent of maximum.

This indicator, calibrated in percentage of motor load, does a more direct job when used with machine tools than the conventional ammeter. The highly damped instrument eliminates needle waver due to vibration or minor load changes. Dual voltage units are adjustable for operation on either 220 or 440 v systems. Machinery Electrification, Inc., Dept. SRR, Northboro, Mass.

Circle No. 19 on reply card



**SPECTROSCOPIC** analysis with simple instrument.

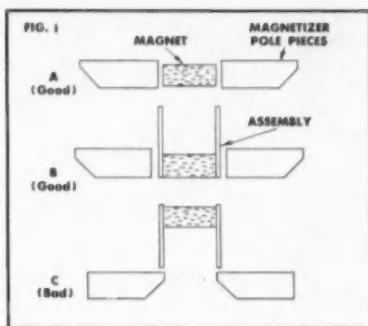
Spectroscopic analysis of gaseous or chemical constituents by emission, transmission, or absorption can be performed by non-technical personnel with the simple dial and meter arrangement shown above. Narrow-band infrared, ultra-violet, or visible filters can be handled. Axler Associates, Inc., 102-42 43rd Ave., Corona, N. Y.

Circle No. 20 on reply card

# INDIANA PERMANENT MAGNET DESIGN INFORMATION

published for industrial and consumer  
product engineers and designers

## HOW TO MAGNETIZE PERMANENT MAGNETS



Magnetizing permanent magnets after assembly into the product offers several advantages. Higher field strengths are obtainable. The magnetic field produced in a loudspeaker, for example, using an Alnico V permanent magnet that has been magnetized after assembly, is about three times as great as the field obtained when the same magnet is magnetized before assembly.

The unmagnetized magnets are easier to handle and to assemble with other parts of the assembly. There is less contamination due to pick-up of magnetic particles.

Magnetizing after assembly is also advantageous in such applications as watt hour meters, polarized relays, and permanent magnet motors.

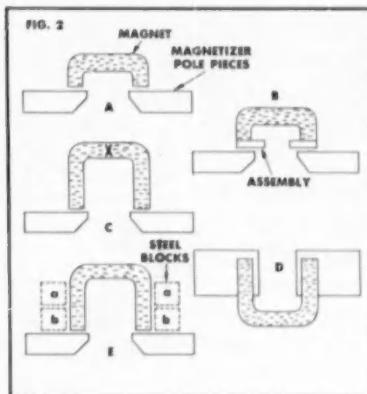
### Using the Magnetizer

Most commonly used magnets are of simple bar or "U" shapes, which may be magnetized with an electro-magnetic magnetizer in the user's plant.

Fig. 1-A shows how a bar magnet should be positioned between the magnetizer's pole pieces. The square ends of the pole pieces are used toward the gap. The space between the pole pieces is adjusted so the magnet can be easily inserted and removed. Normally, only one to two seconds are required to fully magnetize the magnet.

An assembly consisting of a bar-type magnet and soft-steel pole pieces should be placed with the magnet between the magnetizer pole pieces as shown in Fig. 1-B. Positioning the assembly as shown in Fig. 1-C will not fully saturate the magnet.

"U" shaped magnets and assemblies should be positioned as shown in Fig. 2, with the tapered ends of the magnetizer pole pieces used toward the gap. A meter or separator assembly would be placed on the magnetizer as shown in Fig. 2-B.



When a "U" shaped magnet is tall or larger than the generally accepted setting of the magnetizer, the field produced at point "X" (see Fig. 2-C) may not be sufficient to saturate the magnet. In this case there are two acceptable methods of magnetization. One is to place the magnet with its side on the pole pieces as shown in Fig. 2-D. This allows the yoke of the magnet to become magnetized. The magnet is then raised to the position in Fig. 2-C and again magnetized.

The other procedure is to stand the magnet on the magnetizer pole pieces with one or two steel blocks against each of its legs as shown in Fig. 2-E. The magnet (or assembly) is then magnetized three times: first, with both pairs of blocks in place; second, with

blocks (a) removed; and third, with blocks (b) also removed.

For a complete discussion of how to magnetize permanent magnets by the electro-magnetic method, write for a copy of *Applied Magnetics*, Vol. 2, No. 3.



### Chesterfield?

Cigarette manufacturers invest a great deal of time and money to bring you the best smoke possible.

Chesterfield is no exception . . . and strangely enough, behind some of their recent efforts is an Indiana Permanent Magnet. You've probably read dozens of ads which say, "Chesterfield . . . made the modern way . . . with AccuRay."

AccuRay is a machine, made by Industrial Nucleonics Corp., that checks and controls the making of Chesterfields. One of the basic parts of this machine is a contact meter-relay, manufactured by Assembly Products, Inc. And the heart of this relay is an Indiana Hyflux Alnico V magnet!

### Report on Index I Ceramic Permanent Magnets

This recently published four-page technical bulletin, "Indox I Ceramic Permanent Magnets," suggests factors to be considered during design calculations, and discusses possibilities for new applications or improvements of existing ones.

Also discussed are some 30 representative sizes and shapes available in sample quantities for immediate shipment. Ask for price list and Catalog 15-P-1.

THE INDIANA STEEL PRODUCTS COMPANY  
Valparaiso, Indiana

WORLD'S LARGEST MANUFACTURER OF PERMANENT MAGNETS

INDIANA  
PERMANENT  
MAGNETS

"it's  
a  
call  
from"  
**PHILLIPS**



How helpful to a busy engineer is that sooner-than-expected report: "We've found the trouble!", "We can ship Friday!" or "I'm flying the prints out tonight!". Phillips customers are used to that help — a unique combination of engineering skill\* and personal attention. We call it the *Phillips Plan*. To enjoy that extra service, write us, or call your local man from Phillips.

**\*FOR EXAMPLE:**

*Phillips Engineered Relays*  
are used by the aircraft  
industry in automatic fire  
control equipment, and  
in propeller synchronizers  
for multi-engine planes.



20493 TYPE 4 — Hermetically-sealed miniature relay. Three stud mounting, maximum 14 pins, solder terminals. O.D. 1 1/8" H x 2 1/8" L x 1 1/8" W.



TYPE 33BQA / TYPE  
33BAC — all-purpose  
power relay, five pole.  
O.D. 2 1/8" L x 2" W x  
2 1/8" H.



20445 TYPE 27QA —  
Hermetically-sealed power  
relay, three pole. Four  
stud mounting. O.D.  
2 1/8" W x 2 3/8" L x 3 1/8" H.

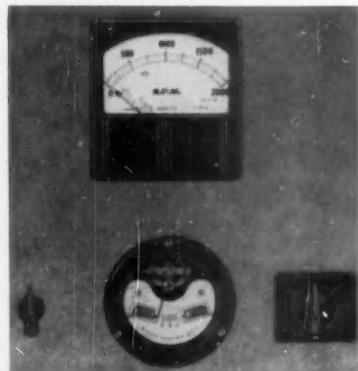
**NEW PRODUCTS**



**MICROSEC DELAYS**  
accurately generated.

Duration of waveforms, pulse widths, delay characteristics of oscilloscope amplifiers, and other time-basis functions can be measured with the aid of the time delay generator shown above. The Type 326 has three overlapping ranges from 1.5 microsec to 10,000 microsec. Low impedance of trigger output minimizes loading effect of equipment triggered. Its output is two pulses, one delayed. The delayed output triggering pulse has a 50 v minimum and a rise time of 0.15 microsec with a width, at 50 per cent of maximum, of 0.5 microsec. Allen B. Du Mont Laboratories, Inc., 750 Bloomfield Ave., Clifton, N. J.

Circle No. 21 on reply card



**SPEED INDICATOR** sensitive  
to small rpm variations.

Use of the Weston Frequency Responsive system allows the machine shown above to detect motor speed changes in automatically regulated systems. A tachometer indicator is provided to give visual indication of the full speed range. Speed changes as

MULTI-CONTACT, POWER, HERMETICALLY SEALED RELAYS ACTUATORS

**PHILLIPS**

PHILLIPS CONTROL CORPORATION . . . JOLIET, ILLINOIS

SALES OFFICES: NEW YORK - PHILADELPHIA - BUFFALO - SAN FRANCISCO - DENVER  
SANTA MONICA - ATLANTA - DETROIT - CLEVELAND - DALLAS - SEATTLE

## NEW PRODUCTS

small as  $\frac{1}{4}$  of 1 per cent will be indicated for speeds as high as 80,000 rpm. Lack of vacuum tubes means maintenance-free operation, says the maker. Weston Electrical Instrument Corp., 614 Frelinghuysen Ave., Newark 5, N. J.

Circle No. 22 on reply card



### DC AMPLIFIER uses chopper for stabilization.

The chopper stabilized dc amplifier shown here provides less than 2 mv drift through 40 hrs. The maker says this is accomplished through a chopper stabilization circuit—and with noise less than 5 microvolts, peak to peak at input, 3 cycle band, less than 5 microvolts rms for 750 cycle band, and less than 12 microvolts rms for 50 kc band. Gain remains constant to within 3 db from dc to 30 kc. Output is 25 with a 1,000 ohm load, with linearity better than 0.1 per cent. More information on the Model 110 dc amplifier is available from Kay Lab, Box 16, San Diego 12, Calif.

Circle No. 23 on reply card



### LOW PRICED and small sized, recorder is portable.

The portable recorder shown above has advantages of low price and fast

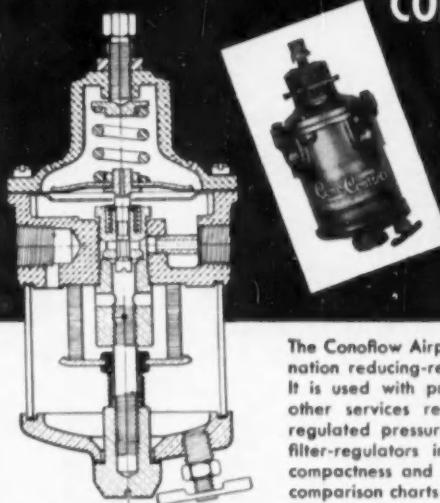
## COMPARISON PROVES...

### CONOFLOW AIRPAK FILTER-REGULATOR

### LEADS the FIELD

in

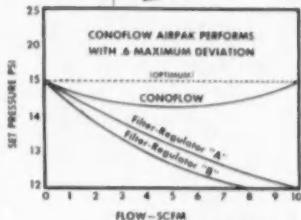
- ✓ DESIGN
- ✓ PERFORMANCE
- ✓ LONG LIFE OPERATION



The Conoflow Airpak is a moderately priced combination reducing-relief type regulator and air filter. It is used with pneumatic controllers and in many other services requiring clean, filtered air at a regulated pressure. The Airpak surpasses all other filter-regulators in its price range for efficiency, compactness and all-around ruggedness. Check the comparison charts below:

#### DROOP CURVES

Smooth performing instruments demand a constant regulated air supply. The flat droop curve of the Airpak proves its superiority over two other name brand units.



#### DESIGN COMPARISON CHART

|   | Conoflow Model FH-20 Airpak              | Filter-Regulator "A"                            | Filter-Regulator "B"                             |
|---|--|---|--|
| 1. Number of Outlets for multiple connections | 3  | 2   | 1  |
| 2. Filter Thickness                           | $\frac{1}{4}$ "                          | $\frac{3}{16}$ "                                | $\frac{1}{8}$ "                                  |
| 3. Inner Valve                                | Polished Stainless Steel—Guided          | Rubber Coated Brass—Not Guided                  | Rubber Coated Brass—Guided                       |
| 4. Dripwell Capacity                          | 9-27 cu. in. (variable)                  | $6\frac{1}{2}$ cu. in. (not variable)           | $4\frac{1}{2}$ cu. in. (not variable)            |
| 5. Assembly                                   | Standard Screw Driver only tool required | Phillips Screw Driver and Allen Wrench (1 bolt) | Standard Screw Driver and Allen Wrench (4 bolts) |

The Airpak gives longer, trouble-free service because of its rugged construction including forged brass and stainless steel inner valve, assuring maximum resistance to corrosion and erosion. The larger filter and dripwell provide extended dependable operation without servicing. A standard screw driver is all that is required for quick, easy teardown because of the Airpak's unique, single-bolt construction.

Make your own comparison and you will see why companies like duPont, Leeds & Northrup, Bristol, Honeywell, Sheffield, Builders Iron Foundry, M. W. Kellogg and many others have learned to rely on the Conoflow Airpak.

WRITE FOR BULLETIN H-2 CONOFLOW PNEUMATIC REGULATORS

C-600

*Cono-Controls*

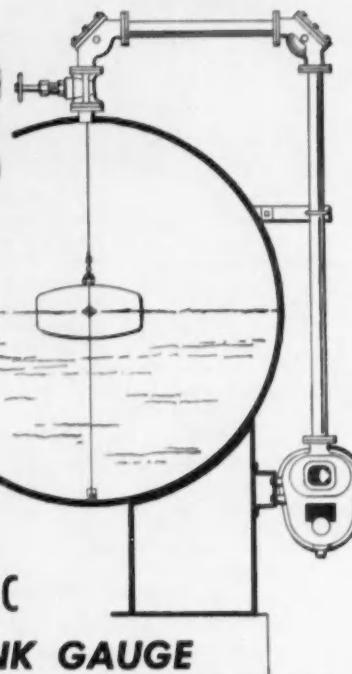
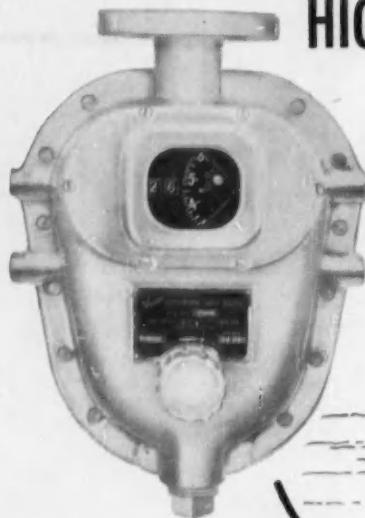
CONOFLOW CORPORATION

Foremost Manufacturers of Final Control Elements

2100 Arch Street

Philadelphia 3, Pa.

# NOW- Available for HIGH PRESSURE SERVICE



**VAREC**  
**fig. 2500c**  
**AUTOMATIC TANK GAUGE**

Service in working pressures to 300 p.s.i.g. is offered by the new VAREC Figure 2500C Automatic Tank Gauge. It's a high pressure model of the successful VAREC Figure 2500 Series, equipped with the Neg'ator motor, which eliminates use of counter-weight and simplifies installation. This series has been tested by 3 years of service in the Petroleum and Chemical fields, after 2 years of experimental and development work.

An important part of this new model is the magnetic drive, which requires no packing gland or mechanical seal on rotating shaft. The use of stainless steel ball bearing construction throughout provides a combination that reduces friction to a minimum.

Liquid level indication on a mechanical counter and dial for convenient, easy reading. Components are enclosed in a separate compartment to keep tank vapors from fogging dial. Operation checker is standard equipment.

Like the low pressure series Figure 2500 gauges, addition of remote gauges transmitter or control devices is a simple field installation. It is not necessary to remove the gauge head or disturb the original installation in any way.



**VAPOR RECOVERY SYSTEMS COMPANY**

2820 North Alameda Street

Compton 1, California

Cable address: VAREC COMPTON Calif. (U.S.A.) All Codes

961-9

## NEW PRODUCTS

pen speed— $\frac{1}{2}$  sec for full travel across the 5 in. wide chart. It is divided into two cases, weighing 25 lb all told, and operates on control signals in the millivolt range. Machine Products & Engineering Co., Div. of Welltab, Inc., 1713 Yale Blvd., S.E., Albuquerque, N. Mex.

**Circle No. 24** on reply card

**RADIATION MONITOR:** A new area monitor, intended for use around reactors, records gamma and beta radiation separately on a strip chart recorder. A variety of rate ranges are available in the drift-stabilized machine. Trott Electronics Co., 27 Gorham St., Rochester 5, N. Y.

**Circle No. 25** on reply card

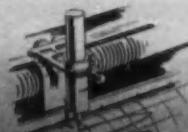
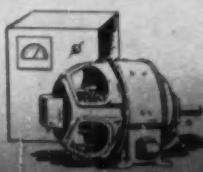
## CONTROL VALVES



**SOLENOID VALVE** has three packless parts.

Shown outside the device above (a three-way solenoid-operated valve) is its three moving parts. Its rate is 400 cycles per min. It easily adjusts to normally open or normally closed operation and is said to handle liquids or gases without leakage. Pipe sizes of  $\frac{1}{2}$  or  $\frac{1}{4}$  in. are accommodated. Either ac or dc coils are available. The unit can be completely cleaned and its parts replaced without removing the whole valve from its pipe line. Automatic Switch Co., 391 Lakeside Ave., Orange, N. J.

**Circle No. 26** on reply card

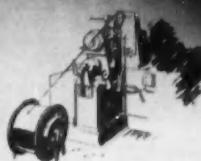


## WHEN LONG-LIFE PLUS IS ESSENTIAL



SPECIFY RCA  
"SPECIAL  
REDS"

...electron tubes with  
10,000 hour minimum life warranty!



RCA "Special Reds" provide that extra "life-line" you need in industrial electronic equipment, air, marine, and land-mobile communications, and unattended relay and transmission circuits—that extra margin of safety and dependability that *keeps things going!*

RCA "Special Reds" feature remarkable *stability*, excellent resistance to shock and vibration, exceptional *uniformity* of characteristics from tube to tube—and are backed by RCA for 10,000 hours minimum life!

RCA "Special Reds" are recommended for initial designs in industrial electronic equipment. They are excellent as replacements in existing circuits where there is a prototype operating under conditions within the ratings of the "Special Reds."

CONTACT YOUR LOCAL RCA TUBE DISTRIBUTOR TODAY. Ask for your free copy of the booklet "RCA Receiving Type Tubes for Industry and Communications" (form RIT-104).

**RCA-5690**—Full-Wave Vacuum Rectifier with separate heaters and cathodes.

**RCA-5691**—High-Mu Twin Triode. Similar to the RCA-6SL7-GT, but has twice the heater current.

**RCA-5692**—Medium-Mu Twin Triode. Similar to the RCA-6SN7-GTB.

**RCA-693**—Sharp-Cutoff Pentode. Similar to the RCA-6SJ7.



**ELECTRON TUBES**

RADIO CORPORATION OF AMERICA

The "Ceramo" thermocouples to be used to measure temperatures for evaluation of efficiency and safety of the "Seawolf's" atomic reactors have Stainless Steel sheaths and Chromel-Alumel thermocouple wires.



**T-E'S NEW "Ceramo" THERMOCOUPLES WILL BE USED TO CHECK REACTOR TEMPERATURES ON ATOMIC SUB "SEAWOLF."**

Where the conditions are the toughest—where heat, corrosion and radiation have made it difficult to write a specification—you can depend on finding "Ceramo" thermocouples. The "Ceramo" sensing element of this new Thermo Electric thermocouple consists of a metal sheath, protecting two thermocouple wire conductors which are separated and firmly fixed in place by ceramic insulation.

Although this thermocouple is rugged enough to stand pressures of several thousand p.s.i. and temperatures to 1600° F., it may be bent to any configuration. "Ceramo" thermocouple extension wire is also available, in all standard thermocouple materials . . . comes in sizes from 1/16" to 1/4" diameter.

Get all the latest information on these new metal-clad, ceramic-insulated wires and thermocouples. Write for Bulletin 31-300-B.



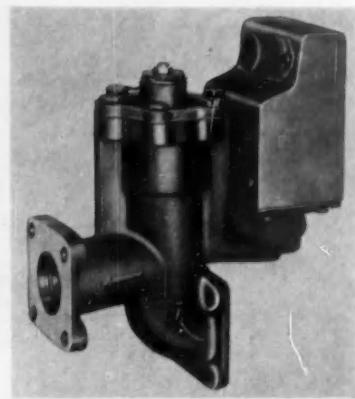
\*Photo Courtesy Electric Boat Division of General Dynamics Corp. and U. S. Navy

**Pyrometers • Temperature Monitoring Systems • Thermocouples • Protection Tubes  
Quick-Coupling Connectors and Panels • Thermocouple and Extension Wires**

**Thermo Electric Co., Inc.**

Rochelle Park Post Office, SADDLE BROOK, NEW JERSEY  
IN CANADA—THERMO ELECTRIC (Canada) Ltd., BRAMPTON, ONTARIO

## NEW PRODUCTS



**SOLENOID-TRIPPED valve is a pressure regulator.**

Wide variations in air pressure or temperature have little effect on the performance of this pressure regulating valve. It holds downstream air pressure constant by means of a pilot-operated main valve. A solenoid bleed valve overrides the operation of the piston pilot to close the main valve, which is of the globe type. It takes unusually high temperatures: 1,000 deg F inlet plus 500 deg ambient Hydro-Aire, Inc., 3000 Winona Ave., Burbank, Calif.

**Circle No. 27 on reply card**

**SOLENOID VALVE LINE:** Conforming to JIC standards is a line of solenoid valves that are inoperable when their covers are removed and that can be manually operated otherwise. Pipe sizes accommodated are  $\frac{1}{4}$ ,  $\frac{3}{8}$ , and  $\frac{1}{2}$  in. Automatic Valve Co., 37415 Grand River, Farmington, Mich.

**Circle No. 28 on reply card**



**VALVE ACTUATOR "fails safe" because of double chamber.**

The valve actuator above features "fail safe" operation. If the operating air or gas pressure fails, the device will return the valve it controls to a set position. This action is accomplished

through the use of two chambers separated by a diaphragm. The diaphragm provides the means for moving the actuation rod. The second chamber accumulates pressure from the first to force the diaphragm to its starting position, should the pressure fail. Required pressure is from 15 to 100 lb. Bettis Corp., 320 S. 66th St., Houston, Tex.

Circle No. 29 on reply card

**CHECK VALVE:** A new pilot-operated check valve for use with  $\frac{1}{2}$ -in. piping in industrial oil-hydraulic systems utilizes spring-closed poppet type construction. These valves can be used to flow in a given direction until opened by a remotely controlled pilot pressure. The rated capacity of the new 4 CG-03 line is 8 gpm. They are for systems with line pressures of up to 2000 psi. The pilot pressure required is greater than 40 per cent of the system pressure. Vickers Inc., Detroit 32, Mich.

Circle No. 30 on reply card

## PULSE PRODUCTS

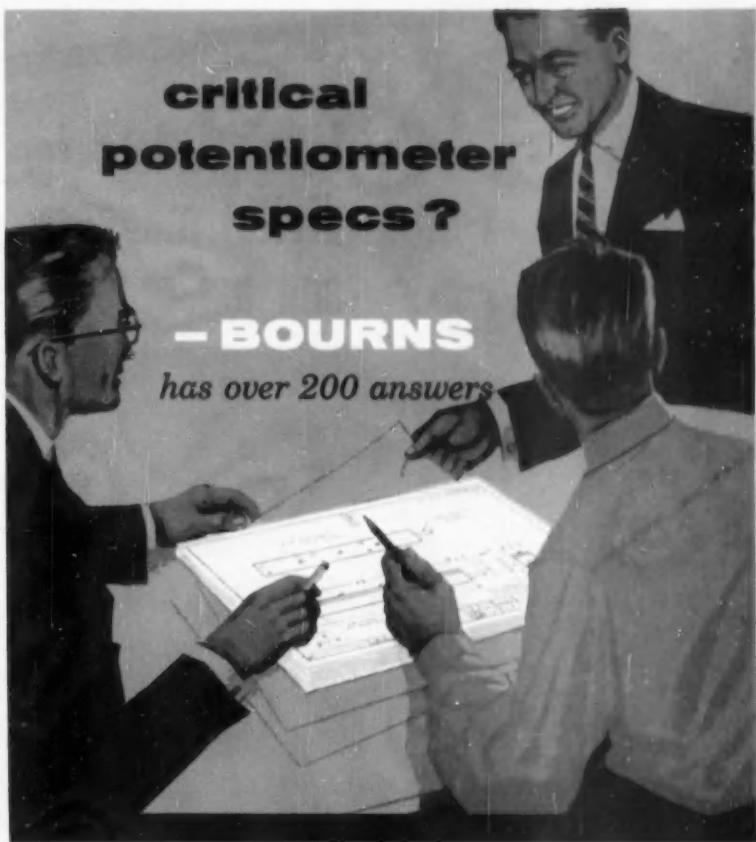


### DIRECT READING counter dial indicates up to 100 turns.

Plain to see, the dial above provides direct-reading ease in identifying the position of multi-turn potentiometer shafts. It affords readings to 9999 with up to 100 turns and is  $1\frac{1}{2}$  in. deep by  $\frac{1}{4}$  diam. Amerac, Inc., 116 Topsfield Rd., Wenham, Mass.

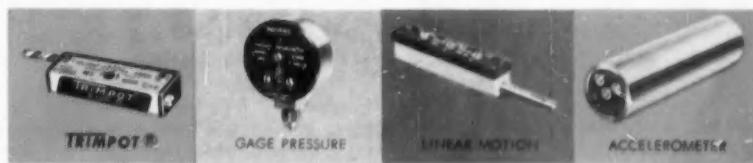
Circle No. 31 on reply card

**PNEUMATIC OSCILLATOR:** A new pneumatic square wave generator is said to contain no moving parts. It is adjustable through a frequency range of from 3 to 50 cycles per min. Output amplitude can be from 0 to 30 psi, and top frequencies of 300



**To fit numerous applications.** Bourns has 200 designs of miniaturized, high-performance sensing instruments on file. These designs are either standard types, or variations made to meet critical electrical and environmental specifications. The pressure potentiometer designs range from  $\frac{1}{2}$  to 10,000 p.s.i. Linear motion units provide travels of  $\frac{1}{8}$ " to 30", and you can choose from a wide variety of resistance ranges.

**The instrument you need** may be among these Bourns designs—ready for production from parts in stock. Or one of the designs now on our boards may meet your specs. If not, we will gladly consider developing the instrument you require. Send us your specifications—your problem may already be solved.



**BOURNS LABORATORIES**

6135 Magnolia Avenue, Riverside, California  
Technical Bulletins on Request, Dept. 12

## NEW PRODUCTS



### headquarters for digital magnetic and perforated tape handlers

**Model 902 Magnetic Tape Handler** treats the tape gently while providing a start/stop time of 5-milliseconds. Fully reversible without stopping.

**Model 903 Perforated Tape Reader** provides a 5 millisecond start time and stops on the character at 300 characters per second and on the character following a stop code at 600 characters per second.

**The Potter Digital Magnetic Head** eliminates "digit drop-outs" due to oxide collection. Phosphor bronze head mount provides close tolerances insuring complete interchangeability of tape from one machine to another.

**Whether your data processing requirements call for perforated or magnetic tape handling, Potter offers a complete line of high-speed equipment to meet your needs . . . for either intermittent or continuous playback with speeds of up to 60 inches per second and start/stop times of less than 5-milliseconds!**

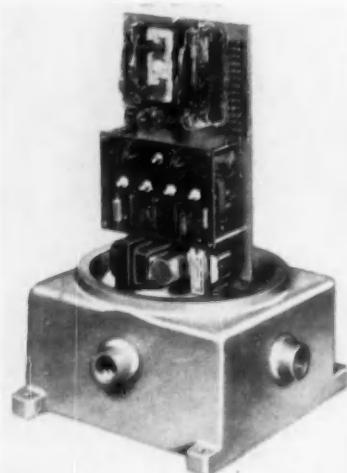
**Servo-controlled tape drives** permit fast starts and stops without tearing or spilling tapes. At 30 inches/second speed, less than  $\frac{1}{8}$ " of tape is consumed in a start/stop cycle!

**For complete specifications on Perforated Tape Readers, Magnetic Tape Handlers and Digital Magnetic Recording and Playback Heads, write TODAY:**

**POTTER INSTRUMENT CO., INC.**  
115 Cutter Mill Road  
Great Neck, New York

cycles per min can be proved for special applications. Servo-Gauge Mfg. Co., 1450 Timber Drive West, Elmhurst, Ill.

**Circle No. 32 on reply card**



### REMOTE temperature reading system uses pulse coding.

A remote temperature reading system called the ST-8900 can operate wherever conventional communication facilities exist. Here's how the remote transmitting station, shown above, operates after receiving a start or command readout pulse from the receiving station: First, a series of pulses begin the temperature reading process. Next, the station transmits a pulse sequence to identify itself. Then, a series of pulses gives a direct indication of the temperature to the nearest degree. The normal span of reading is 130 deg F, but the top temperature measurement may be as high as 500 deg F. Broader spans can be achieved by a proportional lower accuracy. Shand & Jurs Co., Berkeley 10, Calif.

**Circle No. 33 on reply card**

**NEW SCALER:** You can preset a new six decade counter at any of nine intervals ranging from 100 to 1 million counts. It can be set to stop on reaching the preset elapsed time of from 100 to 100,000 sec. Counting rates go up to 60,000 cps. Input resolution is 5 microsec, and input circuit includes a 5 to 50 v pulse height discriminator. American Tradair Corp., 34-01 30th St., Long Island City 6, N. Y.

**Circle No. 34 on reply card**

for accurate, reliable  
automatic control



NOW...



**FIRST to Produce  
Commercially-Available  
Magnetic Amplifiers**

Vickers complete Magnetic Amplifier Systems are developed to meet the need for reliable and accurate control in today's rapidly-expanding field of automatic control in industry.

In addition to custom design systems for particular complex applications, Vickers offers a complete line of standard magnetic amplifiers from milliwatts to 50 kilowatts. For your automatic control needs, Vickers' full resources, including special engineering skills and years of practical experience, are available to assist you in the solution to your problems.



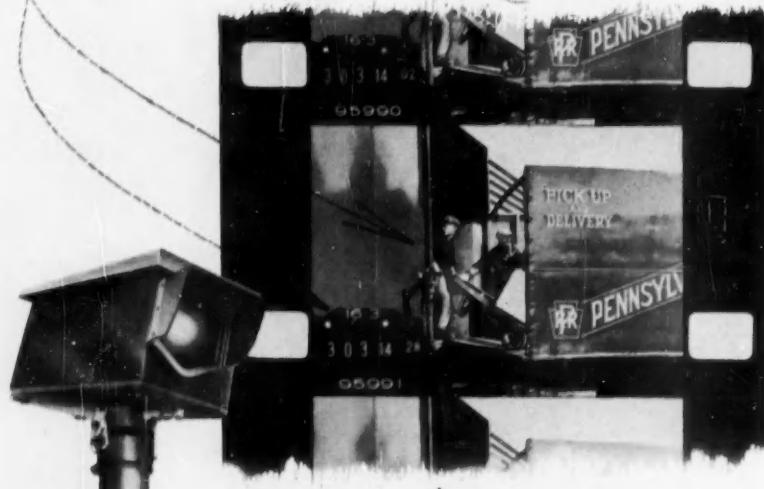
VICKERS ELECTRIC DIVISION

**VICKERS** Inc.

a unit of Sperry Rand Corporation

1805 LOCUST STREET • SAINT LOUIS 3, MISSOURI

1. take pictures of objects  
 2. record pertinent data  
 simultaneously...  
 automatically.... } ON ONE  
 FRAME



## TALLER & COOPER'S automatic **CAMERA**

Automatic classifying and recording has been revolutionized by the Taller & Cooper Automatic Camera. It takes two pictures at once. One of the object to be recorded, and one of pertinent data such as date and time, material identification, pressure, or any other data that can be inscribed on digital counters.

Activated remotely, the film automatically advances to the next frame on completion of picture. Utilizing 16 mm film on 400 foot reels, this camera offers continuous 24 hour service.

With the Taller & Cooper Automatic Camera, you are assured clear photos by means of an automatic iris which *adjusts itself* to varying light conditions.

Fan and heating units are incorporated in this unit when used under extreme temperature variations.

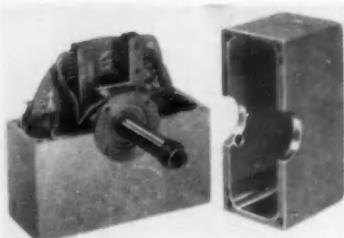
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No. 507 and full details

**TALLER & COOPER, INC.**

ENGINEERS • MANUFACTURERS  
 75 Front St., Brooklyn 1, N. Y.

## NEW PRODUCTS



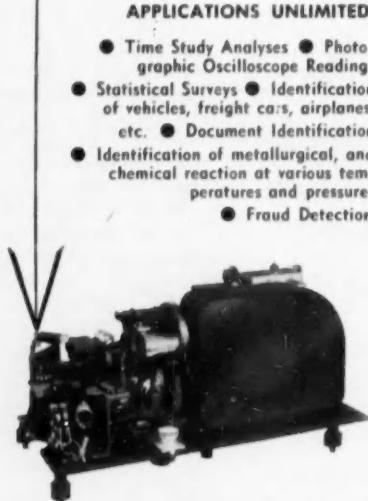
**AN-DIG** converter line has all types of coded discs.

A line of the analog to digital converters similar to the one above is available with either non-ambiguous or incremental coding and in both binary and decimal form. The incremental coded type is available with torque as low as 0.01 oz-in. and a moment of inertia as low as 10 gm cm<sup>2</sup>. Wang Laboratories, Inc., 37 Hurley St., Cambridge, Mass.

Circle No. 35 on reply card

**PULSE AMPLIFIER:** A new linear pulse amplifier includes a regulated power supply, an amplitude discriminator and three high speed binary counters. Its resolving time is one microsec, maximum input rate 100,000 counts per sec. North American Philips Co., Inc., 750 S. Fulton Ave., Mt. Vernon, N. Y.

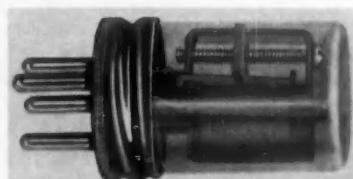
Circle No. 36 on reply card



### APPLICATIONS UNLIMITED:

- Time Study Analyses ● Photographic Oscilloscope Readings
- Statistical Surveys ● Identification of vehicles, freight cars, airplanes, etc. ● Document Identification
- Identification of metallurgical, and chemical reaction at various temperatures and pressures
- Fraud Detection

## RELAYS & SWITCHES



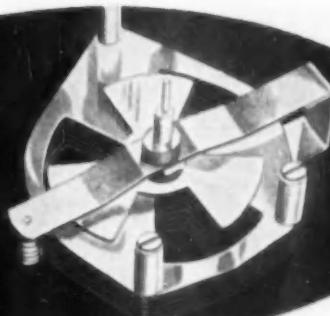
**FREQUENCY OPERATED** relays make multiplexing easy.

A new series of low-cost TR frequency-operated relays operate in frequencies ranging from 40 to 170 cps with a 400 ohm coil as standard. A maximum of ten relays can be separately operated by appropriate control tones on a single circuit. Potter & Brumfield, Princeton, Ind.

Circle No. 37 on reply card

- CONTROL EQUIPMENT & SYSTEMS
- DIGITAL COMPUTERS
- TOLL COLLECTION SYSTEMS
- WIND TUNNEL INSTRUMENTATION
- SPECIAL PURPOSE PRINTERS & INSTRUMENTATION
- CHEMICAL ANALYZERS & CONTROL EQUIPMENT

In DYNALOG Instruments, a simple, variable, radio-type capacitor replaces the troublesome slide-wire — gives unmatched smoothness of balancing.



This potentiometer has no slide-wire

**STEPLESS  
CAPACITY-BALANCING  
ELIMINATES  
SLIDEWIRE  
MAINTENANCE**

There's no need to put up with worn slide-wires and sticking electrical contacts . . . no need to periodically clean and lubricate balancing motors. DYNALOG design eliminates all this! Its simple variable capacitor and positive magnetic drive provide *continuous, stepless* balancing . . . *never* require attention!

DYNALOG's friction-free action provides high speed of response without wear. (There are only five moving parts, including the

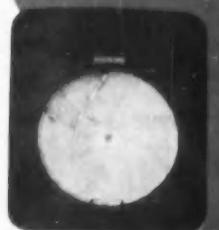
recording pen!) Sensitivity, unlimited by turns of slide-wire winding, is 1/100 of 1%. And accuracy is a sustained 1/4 of 1%.

DYNALOG Instruments are available for use with resistance, voltage, capacity, or inductive type primary elements to measure and/or control any process variable . . . with unmatched smoothness. Write for Bulletin 427. The Foxboro Company, 361 Norfolk Ave., Foxboro, Mass., U.S.A.

\*Reg. U.S. Pat. Off.

**DYNALOG'S\*  
EXCLUSIVE  
BALANCING  
ACTION**

- \* no slide-wire
- \* no batteries
- \* no standardizing
- \* no gears, cables, etc.
- \* no high-speed reversing motor

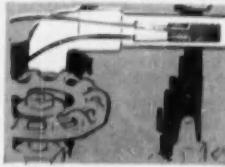


**FOXBORO**  
\*Reg. U.S. Pat. Off.  
**DYNALOG**  
ELECTRONIC  INSTRUMENTS

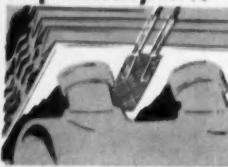


**RESISTANCE THERMOMETER ELEMENTS  
For Quick, Low-Cost  
SURFACE TEMPERATURE  
MEASUREMENT and CONTROL**

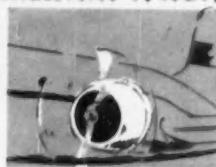
RdF Stikons bond easily to practically ANY surface ANYWHERE



Cylindrical Surfaces in the Food, Chemical, and Petroleum Processing Industries, utilizing existing installations.



Hard-To-Reach Flat Surfaces Inside Ducts and Heat Exchangers in the Aircraft, Automotive, and Chemical Industries without affecting the flow of the fluids.



Rounded Surfaces on Engine Cowls in the Aircraft Industry with minimum obstruction to airflow.

Used for research and manufacture in all fields of temperature measurement and control, an RdF Stikon consists of a temperature-sensitive grid of very fine nickel wire bonded into a paper-thin wafer of flexible, insulating material. Bonded by cement to almost any surface anywhere, an RdF Stikon is unaffected by shock or vibration. Its response to temperature change is extremely fast and amazingly accurate. The thinness of the RdF Stikon (.0005" to .010") opens up applications difficult or impossible with other thermal-sensing elements. In addition to the standard RdF Stikons tabulated below, special resistance-thermometer elements are tailored to specific customer needs.

| Type | Resistance at 70°F (ohms) | Temperature Range F° | Wafer Material | Size (Inches)        |
|------|---------------------------|----------------------|----------------|----------------------|
| BN-1 | 81.7                      | -100° to +300°       | Bakelite       | 1/2 x 1 1/2 x .005   |
| BN-3 | 50.                       | -100° to +300°       | Bakelite       | 5/16 x 3/4 x .006    |
| BN-4 | 200.                      | -100° to +300°       | Bakelite       | 5/16 x 7/8 x .006    |
| PN-1 | 50.                       | -100° to +180°       | Paper          | 5/16 x 3/4 x .006    |
| PN-2 | 200.                      | -100° to +180°       | Paper          | 5/16 x 7/8 x .006    |
| SN-1 | 100.                      | -100° to +500°       | Silicon-Glass  | 5/16 x 1 1/16 x .010 |

Send for our FREE Temperature Measurement and Control Brochure Today.

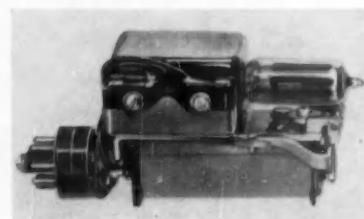
ARTHUR C. RUGE ASSOCIATES, INC.

CAMBRIDGE 38, MASSACHUSETTS

**NEW PRODUCTS**

**HEAVY LOAD MINIATURE RELAY:** Contacts rated up to 20 amps are featured in a walnut-sized relay recently offered. Minimum coil operating power is 1 watt. Contact arrangement is single pole single throw. Magnecraft Electric Co., 3352 W. Grand Ave., Chicago 51, Ill.

Circle No. 38 on reply card



**SENSITIVE RELAY** carries its own built-on amplifier.

Currents as small as 15 millionths of an ampere will operate the relay shown above. The secret is the small amplifier on the back of the device. The result is current amplifications on the order of 10 million to one. Input power is less than 0.00011 watts, while the output can handle up to 1,150 watts. Ordinary 115 vac power operates the cold-cathode tube circuit, which draws no power in the absence of a control signal. Operating speed is about 50 msec. The circuit is potted. Industrial Electronics Co., Inc., Hanover, Mass.

Circle No. 39 on reply card

**IMPULSE COUNT SWITCH:** When it's used as part of a machine tool control, a new preset counter can shut down an operation or station after the number of cycles that experience shows is the limit of a given tool's life. Easily set by a single pointer-type knob, the compact electro-mechanical device steps the knob toward zero with each completed machine cycle. Hagan Mfg. Co., Moline, Ill.

Circle No. 40 on reply card

**ELECTRONIC SWITCH:** The simultaneous presentation of two inputs on one scope is provided in dc to 15 mc operation by a new electronic switch. Both absolute and relative amplitude measurements can be made to within 2 per cent. The amplifier rise time is 0.023 microsec, input 1 megohm, and output impedance 93 ohms. Electronics Laboratory, Inc., 54 Kinkel St., Westbury, N. Y.

Circle No. 41 on reply card

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(100) VARIABLE INDUCTORS. Vari-L Co., Inc., Catalog 9/55, 12 pp., and Bulletin 9/55-S, 12 pp. Describe a saturable-core reactor which is really a variable inductor for tuned circuits. Control current vs. frequency curves plotted.

(101) PLATE PIPE COIL. Thermo-Panel Div. of Dean Products, Inc. Bulletin 256, 4 pp. Dean calls this an improvement on pipe coils. The standard panel consists of two embossed 14-gage rolled steel plates welded together to form flow channels.

(102) VIBRATION MOUNTINGS. Vibration Mountings, Inc. Catalog G-55, 8 pp. Installations range from the heaviest impact machinery to instruments that do not create vibration but are affected by it. Chart helps determine minimum deflection required for a selected isolation efficiency.

(103) DOPPLER DATA TRANSLATOR. Potter Instrument Co., Inc. Data sheet. Describes an instrument that codes and records cyclic tape data on binary magnetic tape for a computer. Rate is 500 samples per sec; recording is continuous.

(104) DEPOSITED CARBON RESISTORS. Electroseal Products, Inc. Technical Information Bulletin 100, one sheet.

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CONTROL ENGINEERING

JANUARY, 1956

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POSITION \_\_\_\_\_

COMPANY \_\_\_\_\_

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| 28  | 29  | 30  | 31  | 32  | 33  | 34  | 35  | 36  |
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| 145 | 146 | 147 | 148 | 149 | 150 | 151 | 152 | 153 |

CONTROL ENGINEERING

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COMPANY \_\_\_\_\_

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CITY AND STATE \_\_\_\_\_

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Shows high-frequency response and temperature coefficient curves for axial and radial lead resistors. Tolerance 2, 5, or 10 per cent, noise factor minimal, wattage ratings conservative.

(105) POTENTIOMETER. The Bristol Co. Bulletin PI270. Describes the new high-speed recording Dynamaster pot. Recorder has full-scale pen travel across its 11-in. calibrated chart of only 0.4 sec.

(106) AN CONNECTOR CHART. The Deutsch Co. Wall chart, 22 x 28 in. Groups connectors by inserts, shells, and contact size, voltage rating, creepage, and spacing, and tells how to specify a complete connector assembly.

(107) PNEUMATIC REGULATORS. Conoflow Corp. Bulletin H-2, 8 pp. The pneumatic equipment described here includes filter-regulator combinations, relays, purge assemblies, and control panels. Cross-section and dimension drawings.

(108) PROCESS REFRACTOMETER. Consolidated Engineering Corp. Bulletin 1839, 8 pp. This Phillips Petroleum development records and controls by measuring the difference in refractive index between a standard and a sample.

(109) HYDRAULIC OIL PUMP. Lear-

Romes Div. of Lear, Inc. Product Data Sheet 5-45, one page. Tells about a light (2.6 lb) and rugged aircraft pump for ambient temperatures of minus 65 to plus 165 deg. F. Rated capacity is 2 gpm at 3,750 rpm and 1,500 psi. Input is 2 hp.

(110) AIRBORNE CONNECTOR. Electronic Sales Div. of DeJUR-Amsco Corp. Bulletin CCC20, one sheet. Shows actual size of this miniature, lightweight, versatile unit. All dimensions clearly tabulated.

(111) PRESSURE DIFFERENCE TRANSMITTER. Hagan Corp. Bulletin MSP-130, 4 pp. Hagan says this instrument fills the need for transmitters that can measure in ranges exceeding several hundred pounds per square inch. It's usable at static pressures up to 3,000 psi.

(112) CLUTCHES & BRAKES. Dial Products Co. Catalog 955, 8 pp. These electromagnetic devices have OD's ranging from 0.920 to 1.500 in. and torque values up to 200 in.-oz.

(113) CONTROL VALVE OPERATOR. Industrial Controls Div. of Manning, Maxwell & Moore, Inc. No compressed air is needed here, because this item generates its own hydraulic power. Dc signal ranges from 0.5 to 5.0 ma.

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CONTROL ENGINEERING  
330 West 42nd Street  
New York 36, N. Y.



(114) VERSATILE SCOPE EXPANDER. Laboratory for Electronics. Bulletin, 1 page. Suggests a dozen applications for this instrument that are above and beyond its prime duty: expansion of the range of an oscilloscope.

(115) NEW DECKER LITERATURE. Decker Aviation Corp. Six data sheets. Cover Decker's rotor micrometer, capacitance-to-analog transducer, dynamic balancer, ionization transducer, comparator micrometer, and pressure meter.

(116) ELECTRONIC TESTING. Shasta Div. of Beckman Instruments, Inc. Catalog, 8 pp. This instrumentation line includes expanded scale voltmeters and frequency meters, vacuum tube voltmeters, oscillators, resistance bridges, power supplies, wide band amplifiers, a WWV receiver, and a decade inductor.

(117) TEMPERATURE CONTROLS. Burling Instrument Co. Catalog G-20, 4 pp. These differential expansion instruments operate on the bi-metallic principle, though they are not strip-operated thermostats. They handle temperatures ranging from sub-zero to 1,800 deg F.

(118) CONSULTING SERVICES. Cincinnati Research Co. Bulletin, 12 pp.

Describes various ways in which industries can use consultants, and outlines fields of specialization of Cincinnati Research.

(119) ELECTRIC MOTORS. Howell Electric Motors Co. Bulletin N-100-R, 16 pp. Tells about the new Series 100 motors whose ventilation system provides 50 per cent more contact between cooling air and lamination.

(120) SYNCHRONOUS AND INDUCTION MOTOR. Holtzer-Cabot Divs. of National Pneumatic Co., Inc. Bulletin MO-3-5, 4 pp. About a new 3-in. diam motor that develops efficiencies of more than 30 per cent. The rotor in the synchronous model is unique.

(121) RAY PROJECTORS. The M. W. Kellogg Co. Booklet, 24 pp. Discusses sources of gamma radiation and three models of the "Kel-Ray" projector. Ray intensity and exposure guide included.

(122) PUSH-BUTTON ACTUATORS. Micro-Switch Div. of Minneapolis-Honeywell Regulator Co. Data Sheet P99. Describes the new Series 4MA and 5MA switch actuator. Indicates switch actuator series and actuator for specific needs.

(123) TEST EQUIPMENT. Weston Electrical Instrument Corp. Catalog

R36A, 16 pp. The nine communication equipment testing instruments listed here include clamp voltmeters and ammeters, an industrial circuit tester, an electron tube analyzer, an oscilloscope, and a sweep generator.

(124) PHOTOELECTRIC PYROMETER. Electronics Corp. of America. Bulletin PT 556, 4 pp. This photoswitch model responds to temperature changes of 5 deg F without physical contact. Oxides, scale formation, smoke, or vapors do not affect accuracy.

(125) DEPOSITED CARBON RESISTORS. International Resistance Co. Bulletin B-4a, 4 pp. Presents comprehensive data on tests, applications, specs, tolerance, ranges and dimensions.

(126) THERMOCOUPLES. Revere Corp. of America. Engineering Bulletins 1601, 02, 03, and 04, 14 pp. Cover design and selection of thermocouples for liquid, gas, and surface temperature measurements.

(127) ELECTRON TUBES. Industro, Inc. Bulletin A1-55-IOM, 22 pp. Just about 1,000 tubes, arranged according to type, description, code, and list price, are catalogued here.

(128) METERS. Meter & Valve Div. of Rockwell Mfg. Co. Bulletin OG 409, 8 pp. Describes a new line of all-bronze Rotocycle meters (bulk and tank truck models) for industrial use. Flow rates range from 20 to 500 gpm.

(129) HOSE COUPLINGS. Titeflex, Inc. Form 7-55-20, 20 pp. Describes these couplings' simple construction and their unique swiveling action. They seal the line at the instant of disconnect.

(130) TIME DELAY RELAYS. A'G'A Div. of Elastic Stop Nut Corp. Bulletin SD-1, 4 pp. Feature here is a two-page selection chart that matches each Agastat relay with its respective characteristics and the job it is designed to do. Fifty-eight models treated.

(131) FLEXIBLE SHAFT ASSEMBLIES. Kupfrian Mfg. Corp. Catalog 5694, 12 pp. Presents full size illustrations of representative shaft assembly combinations. Tables list properties, dimensions, and tolerances.

(132) CLEAN, DRY AIR. Hankison Corp. Bulletin M-7155, 4 pp. Discusses components and operation of "Condensifilters", which condense and dry compressed air at pressures up to 200 psi. A moisture-vapor content chart evaluates water vapor.

(133) RATE OF FLOW CONTROLLER. Builders-Providence Div. of B-I-F Industries, Inc. Bulletin 600-J9A, 4 pp. These power-actuated units can be positioned by pneumatic, hydraulic, or electric sources. Accuracy is to plus or minus 3 per cent.

(134) AIR GAGING. Pratt & Whitney Div. of Niles-Bement-Pond Co. Circular 586, 24 pp. Covers the Air-O-Limit comparator, a pneumatic back-pressure gage that relates air clearance to part size.

(135) REACTOR SIMULATOR. Leeds & Northrup Co. Folder ND46-70-700(2), 4 pp. Tells how this machine electronically synthesizes most reactor types at a fraction of the cost of building and operating an actual reactor. Photos of components, dc block diagrams included.

(136) DIGITAL READOUT. Coleman Engineering Co., Inc. Technical Bulletin CR-179, 8 pp. This "Digitizer Application Data" covers equipment used with Coleman's an-dig converter. Shows the Digitizer schematic and circuit diagrams of each readout system.

(137) SWITCHES AND AN ACTUATOR. James Cunningham Son & Co., Inc. Bulletins 55-101, 55-102, and 55-111. Discusses two new crossbar switches, one limited to 10 links and 10 lines, that connect circuits in any combination, and a dc electromagnetic solenoid actuator.

(138) CONTROL RELAYS. Clark Controller Co. Bulletin PL 7305-PM, 8 pp. About a new line (10 models) of sectional-pole, heavy-duty 10-amp units with from two to 12 poles. Can take eight poles without double-decking. Each pole (a set of NO or NC contacts) is independent.

(139) ACTUATOR. Weighing Components, Inc. Catalog 22, one sheet. Precisely and speedily positions valves, gates, slides, and other mechanisms electro-hydraulically. Reaction time to an electrical signal is less than 1/1,000 sec.

(140) SELECTOR SWITCH. Electro Tec Corp. Brochure, 4 pp. Distinctions include miniature size, ultra-low torque, and precision. Available with up to 10 positions in a size 10 synchro housing. Can take temperatures ranging from minus 55 to plus 100 deg. C.

(141) DELAY LINES. Helipot Corp. Technical Paper 491, 7 pp. This paper, "Criteria and Test Procedures for Electromagnetic Delay Lines", by Helipot's Norman W. Gaw, Jr., and David Silverman, is the second on these Helidel devices.

(142) FLOWMETERS. Instruments Div. of Scully-Jones & Co. Bulletin, one sheet. Two new models feature a direct flow design whose flexible vane, traveling under flow, indicates on a calibrated scale. Model L is read by a scale, Model LP by inspection of the flow.

(143) INFRARED DETECTORS. Barnes Engineering Co. Bulletin "Optitherm Infrared Detectors", one sheet. Covers characteristics, construction, circuitry, and uses of these high-speed thermistor type sensing elements.

(144) VALVES AND CONTROLS. Associated Valve & Engineering Co. Catalog A-155. Seven sections illustrate more than 100 products for nuclear and chemical industries. Includes capacity charts, tables.

(145) OSCILLOGRAPHIC RECORDING. Sanborn Co. Bulletin 1, 16 pp. Features of these "150" recording systems are their basic assemblies (1-, 2-, 4-, 6- or 8-channels) and their interchangeable preamplifiers.

(146) SUBMINIATURE RELAYS. Elgin-Neomatic, Inc. Brochure, 4 pp. Elgin calls its "neomite" the world's smallest precision relay and the first built in a standard transistor case for transistorized circuitry.

(147) PRINTED WIRING BOARDS. Electronic Components Dept. of General Electric Co. Brochure EP-45, 6 pg. gatefold. Presents layout and design data, specs on base and conductor materials, application characteristics, and advantages.

(148) SELENIUM RECTIFIERS. Rectifier Div. of Sarkes Tarzian, Inc. Selenium rectifier replacement guide (R2) and catalog 4c on the Centre-Kooled SR line.

## DAVIES multi-track magnetic heads for critical data recording/reproducing



NOW... the same multi-track heads developed and manufactured by Davies Laboratories for their own equipment... are available separately for critical recording and reproducing applications. They alone offer these inestimably important advantages:

### Precisely aligned gaps

All gaps lie between two straight lines 0.0003" apart... assuring less than 0.3 mil total scatter.

### Independent track signals

Unique design assures independence of adjacent track signals. Inter-track shields are continuous through the gap line and in contact with tape for absolute minimum cross-talk.

### Ultimate in flexibility

Gap width, nominal inductance, track spacing, and track width of Davies heads can all be varied to requirements. Heads are available with up to 20 tracks per inch for digital recording, 14 tpi for direct and PWM recording, 10 tpi for wide-band FM carrier recording.

### Stability

Heads are embedded in plastic and structurally designed to prevent change of characteristics, even under extreme shock, vibration, temperatures, and humidity.

Exhaustive quality control is your assurance that the characteristics you want are in the head you get. Every Davies magnetic head is rigorously tested against the toughest set of standards ever devised for this type equipment. The five standard series available, offering from 7 to 21 tracks per inch, can be modified to satisfy just about every requirement.

*Complete information on Davies multi-track magnetic data recording-reproducing heads is provided in new Bulletin 55-B. Write now for your personal copy.*



# POWER in a pillbox



## EAD'S new miniaturized 1/8 inch servo-gear motor

For instant response and maximum torque in a miniature package it's EAD's tiny servo-gear motor, precision-designed for applications where size and weight are at a premium. Modifications available in hysteresis-synchronous and induction designs... Tell us your requirement.

Write for our new catalog.

### CHARACTERISTICS

|                 |                           |
|-----------------|---------------------------|
| Input Voltage   | 115                       |
| Phase           | 2                         |
| Frequency       | 400 cycles                |
| No Load Speed   | 180 rpm                   |
| Full Load Speed | 135 rpm                   |
| Rotor Inertia   | 1.25 gm. cm. <sup>2</sup> |
| Stall Torque    | 7 oz. in.                 |
| Rated Torque    | 3 oz. in.                 |
| Size            | 1 1/8" dia.               |
| Gear Reduction  | 2 17/64" long             |
| Weight          | 28.4                      |
| Duty            | 4 1/2 oz.                 |
|                 | Continuous                |

MODEL NO.  
083021H-1

**EAD**

### EASTERN AIR DEVICES, INC.

SOLVING SPECIAL PROBLEMS IS ROUTINE AT EAD



MOTION  
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TACHOMETERS  
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GEAR MOTORS

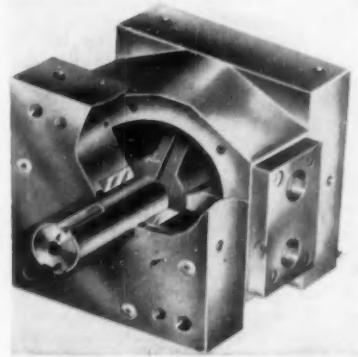
375 CENTRAL AVE., DOVER, NEW HAMPSHIRE

## NEW PRODUCTS

### ROTARY ACTUATORS

**ADJUSTABLE SPEED CONTROL:** A range of motor speeds from 100:1 for motors from  $\frac{1}{2}$  to 4 hp is claimed for the VS-100. Single-phase power supplies the completely packaged and plastic-sealed electronic speed controller. Reliance Electric & Engineering Co., 1088 Ivanhoe Rd., Cleveland 10, Ohio.

Circle No. 42 on reply card



### ROTARY ACTUATOR uses fluid or gaseous medium.

Many jobs requiring intermittent rotary motion, up to 280 deg, might make use of this oscillating torque motor. The Rotamotor operates on air, oil, water, or fire-resistant fluid mediums and is said to be leak-free. Since speed and force exerted depend upon the pressure of the power medium, outputs of either ounces or tons is possible. A fine piece of descriptive literature on the item is available from Roto-Motion Motors, Inc., 525 S. Riverside, St., Clair, Mich.

Circle No. 43 on reply card

**ROTARY AIR MOTOR:** A new model rotary air motor, weighing only 17 lbs delivers 2 hp at speeds up to 2,000 rpm on air line pressures from 30 to 90 psi. Four light vanes automatically take up wear and seal leaks in the new motor. Gast Mfg. Corp., Box 117 N, Benton Harbor, Mich.

Circle No. 44 on reply card



### MAGNETIC SPEED controller provides 50:1 range.

Using simple magnetic circuitry, the motor speed controller seen above is applicable to motors up to 1½ hp. Reversability, dynamic braking, smooth starting, and local or remote control are among the features of the mechanism. The Magne-Speed is available in two sizes from Magnetic Amplifiers, Inc., 632 Tinton Ave., New York 55, N. Y.

Circle No. 45 on reply card

**ROTARY GEAR MOTORS:** Applications requiring up to two hp of rotation may benefit from a new line of fluid motors. A 48:1 speed reducer is available as standard equipment. John S. Barnes Corp., Rockford, Ill.

Circle No. 46 on reply card

### POWER SOURCES



### COMPACT SOURCE gives out standard voltage.

This device, known as the "k-Volt Standard", provides a constant dc output through ambient temperatures as low as minus 55 deg C and up to 100 deg C. The 1½ in. high, 1½ in. diam unit is available with 26.5 vdc or 117 vac or dc to yield an output of 6 v or 1 v at 1 ma or 10 ma. Consumption is less than 1.8 watts. Life expectancy is better than 10,000 hrs and random drift less than 0.1 per cent through 1,000 hrs of operation. Avien, 58-15 Northern Blvd., Woodside 77, N. Y.

Circle No. 47 on reply card

## TRAGEDY IN TWO CHAPTERS

I

Once there was a happy band of people called *Project Engineers*. Mostly human, they had carefree spirits and careworn bodies. Among their number were many with the magical ability that most of us lost when we passed nine years old.



In large and small industrial plants they could be found, dreaming impossible castles and making the dreams come true. How sadly this happy picture was to be shattered, we shall soon see.

The attack was launched insidiously, by The Forces of Darkness, who easily captured citadels of management by firing terms like "specialized knowledge"

and "departmental responsibility" Always noted for an open unsuspicious outlook where *animate* objects are concerned, the Project Engineers saw no bad omen and did their best to cooperate. Specifications of all sorts began dropping around them.

Small thick Military ones on white paper; large limp Departmental ones in purple hectograph; and superlarge Wrinkled ones on single sheets of blue print.

The P. E.'s struggled to give each its due. The result, but for the aforesaid trusting natures, should have put them wise.

Equipment started passing more and more specifications, and doing less and less useful work.

The P. E.'s realized vaguely that all was not right in Denmark. They lost their carefree spirits and their faces bowed down to match their already laboring shoulders.

The F. of D. chose this as the time for the next ploy. "Complexity!", they chortled. "That's the thing — yuk!"

And now equipment blossomed forth in cancerous fashion with thousands and thousands of parts in each set. The F. of D. rubbed their hands! "With three thousand parts (= chances-to-fail), we'll have things g-r-r-round to a standstill in no time."

II

And now comes the real Drama. A small gallant few P. E.'s still with some old time spirit locked horns with a vicious case of complexity. Mercilessly they tortured components piece by piece eliminating each one destined to fail early. As mercilessly they treated finished equipments. They beat the percentages, and made the equipment work, — but at what cost!

They tried to tell others of what they had done, in the city of brotherly love.

But as in any real tragedy, the F. of D. had the inexorable vote of destiny. They made their final overwhelming attack. "We must keep these insufferable undoers of our dastardly doings in the dark. Insulate them from germinal contact with the outside world! Withdraw from them the wisdom available by playing intellectual ping pong with suppliers! Cause them to wither from within by starvation of ideas!"

In no time flat a host of New Harpies were drawn up in cobwebby cadaverous cacophony just out of reach of the Project Engineers. They had names like "Standards Department" — "Qualified Products List" — "Vendor History File" — "AQL".

The last employed survivor of the original happy band resigned last month to join three cronies in a secluded nut hatchery featuring do-it-yourself therapy.



For us, all this is a great shame. We are, as usual, out of step. While we should have been setting up QPL's, we have been doing things like finding out if our hot new little telegraph relays "would work" (Not pass.) It takes time even on a telegraph set to run up half a billion operations. We are now getting back (as exhibits only!) relays which customers have operated in printers (.06 amp. 110 VDC inductive) that many times and more, without even availing themselves of the built-in ingeniously-easy-maintainability.

If only we had been in time, we might have helped reprise a few survivors of the above unequal struggle.



# SIGMA

SIGMA INSTRUMENTS, INC.  
69 Pearl Street, So. Braintree, Boston 85, Mass.

**DC-AC CHOPPERS**

**For 60 Cycle Use**

**Built to rigid commercial specifications.**

**Twenty-two types, both single and double pole.**

**Long life.**

**Low noise level.**

**Extreme reliability.**

**Write for Catalog 370.**

**STEVENS INCORPORATED ARNOLD**

22 ELKINS STREET SOUTH BOSTON 27, MASS.

5/A-10

**Borg 900 Series Micropots**

**offer everything you want in a potentiometer**

- 1 Versatility — 1 to 5 gang models, single or double shaft, servo or bushing mount.
- 2 Permanent Accuracy — Resistance element integrally molded within housing. Leads, taps and terminals firmly encapsulated.
- 3 Long Life — Scanning action distributes wear across face of bar contact. Rigid, fixed lead screw.
- 4 Dependability — Mechanically and electrically stable. Effectively sealed against dust and moisture.
- 5 Absolute Linearity — Uniform resistance distribution. No external trimming required.
- 6 Specifications — Meets extreme commercial and military requirements for all applications.
- 7 Availability — Quick deliveries on production quantities.

#### **Borg 1100 Series Micropots**

Accurate, dependable, long-lived. Has 9 inch coded leads for easy installation. Offers your products a competitive price advantage.

WRITE FOR CATALOG BED-A158

**BORG EQUIPMENT DIVISION**  
GEORGE W. BORG CORPORATION  
JANESVILLE, WISCONSIN

**BORG**  
ELECTRONIC - MECHANICAL EQUIPMENT

*Built by Borg*

#### **NEW PRODUCTS**

**TRANSISTOR CIRCUIT POWER SUPPLY:** Model C-22-2 provides a voltage range of 0 to 30 with a current range of 0 to 2 amps, electronically controlled. Regulation is within 0.1 v, and ripple to within 2 millivolts. Output time constant is approximately 0.1 msec. The internal impedance is held to within 0.05 ohms. Universal Electronics Co., 1720 Twenty-Second St., Santa Monica, Calif.

**Circle No. 48** on reply card

**TRANSISTOR POWER SUPPLY:** A new tubeless power supply, intended for transistor circuit development, offers from 0 to 50 at up to 10 ma on three independent output channels. Ripple is under 1 millivolt and regulation is to within  $\frac{1}{2}$  per cent at 50 v. Higher current models are available. NJE Corp., 345 Carnegie Ave., Kenilworth, N. J.

**Circle No. 49** on reply card

**TRANSISTOR POWER SUPPLY:** From 0 to 100 vdc at 100 ma are offered in a new power supply offering calibrated output. Output can be controlled remotely by inserting a resistor across a two-terminal line. Regulation is to within 0.1 per cent, ripple to within  $\frac{1}{2}$  millivolt, and stability to within 0.15 per cent. Electronic Measurements Co., Lewis St., Eatontown, N. J.

**Circle No. 50** on reply card

#### **ASSORTED HARDWARE**

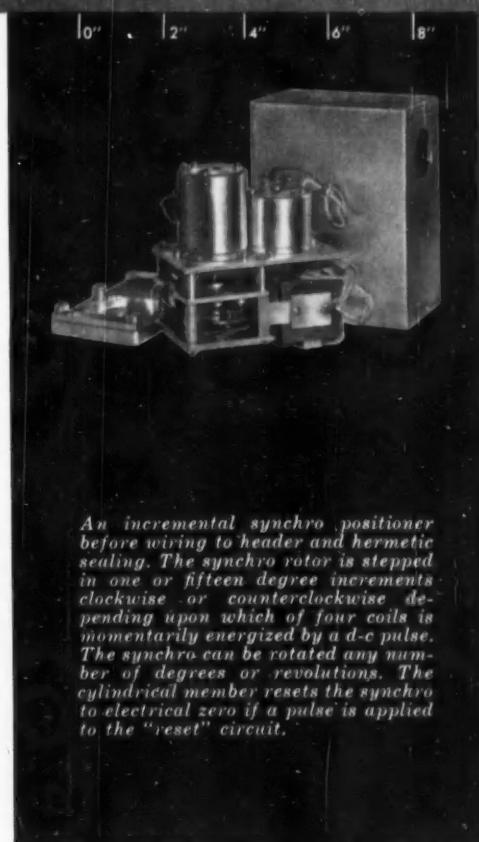


**BASIC BOARD** simplifies printed circuit mockups.

The grommet-filled board above uses conventional wiring techniques to fa-

built to do just one servo control job...

perfectly



Like all Transicoil servo assemblies, this incremental positioner "does the job right" because it was designed for a single application . . . by a company whose major function is to provide complete servo assemblies precisely engineered and manufactured to solve individual servo control problems.

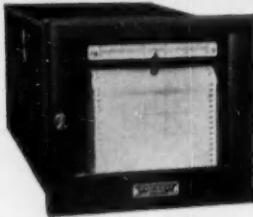
Of course, if you merely want servo components, you'll find Transicoil's control motors, motor-gear train combinations, motor-gear train-generator combinations, and servo amplifiers built to the highest order of precision and accuracy. But it is in the "package" engineering of unique assemblies that Transicoil's experience and creative imagination offer the greatest value. And in most cases, these assemblies cost no more than the individual components would purchased separately.

That's why it pays to check your servo problems out with Transicoil first. Write outlining your problem, and ask for Transicoil's new gear-motor bulletin. You'll find it a mighty handy availability guide in designing for tight production schedules.

**Transicoil**  
CORPORATION

Worcester • Montgomery County • Pennsylvania

## space saver RE C O R D E R at lower cost



The Westronic Model 2705 miniature potentiometer solves your recording needs and control panel space problems. Here are some of the features.

- ★ One second pen travel
- ★ Weighs approximately 25 lbs.
- ★ Guaranteed performance
- ★ Thermocouple or MV. calibrations
- ★ Lower cost
- ★ Panel space 9½" x 8½"
- ★ 5" Strip chart record
- ★ Continuous standardization
- ★ Null balance system
- ★ Accuracy better than 0.5%

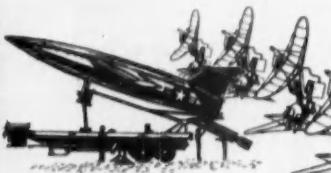
Write for descriptive literature

**westronics, INC.**

3605 McCART STREET ★ FORT WORTH, TEXAS



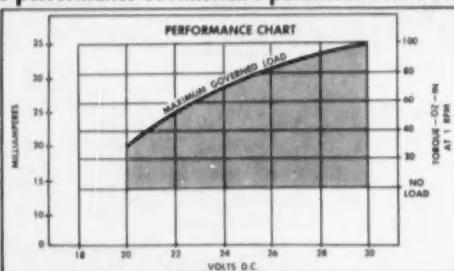
they  
shall  
not  
pass!



### A. W. HAYDON PRECISION GOVERNED 5600 SERIES MOTOR insures performance of America's perimeter defenses.



5600 Series  
GOVERNED  
D. C. MOTOR



**SPECIFICATIONS**

- Voltage range nominal  $\pm$  20% at 68°F.
- Ambient temp. range minus 65°F to plus 165°F.
- Vibration 5-55 cycles per sec. with 10g max. accel.
- Tolerance on escapement rate:
  - $\pm$  0.1% under condition 1
  - $\pm$  0.5% under condition 2
  - $\pm$  0.5% under condition 3
- Shock — per MIL-E-5272A, Proc. 1 (30g for 11ms)

(General  
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*the*  
**A.W.HAYDON**  
COMPANY  
246 NORTH ELM STREET  
WATERSBURY 20, CONNECTICUT

Design and Manufacture of Electro-Mechanical Timing Devices

## NEW PRODUCTS

cilitate breadboarding printed circuits. In addition, it provides a simple base to work on. The Electromatic Co., P. O. Box 827, Wheaton, Maryland.

Circle No. 51 on reply card



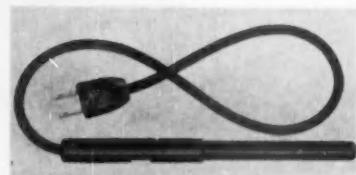
### HOW ABOUT MAKING your own printed circuits?

Here is all you need to make your own printed circuits. In the kit is a 8½-by-5 in. piece of copper-clad laminate and everything needed to etch it. Control Circuits, Inc., 24 Broad St., Middletown, Conn.

Circle No. 52 on reply card

**SUB-MINIATURE RESISTORS:** A new line of resistors for transistorized or subminiature circuitry, only  $\frac{1}{4}$  in. long and  $\frac{1}{16}$  in. diam., offers resistances from 0.1 to 0.5 megohm. Standard tolerances are within  $\frac{1}{10}$  to  $\frac{1}{5}$  per cent. Temperature coefficient is 20 ppm per deg C. The little resistors are wire-wound and available with either inductive or non-inductive windings. Precision Resistor Co., Inc., 107 U.S. Highway #22, Hillside 5, N. J.

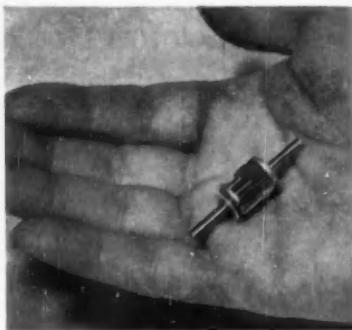
Circle No. 53 on reply card



### PEN-LIKE DEVICE erases spots on magnetic tape.

This little machine, about the size of a king-sized fountain pen, erases small sections of magnetic recordings. The "Magnetic Erasing Pencil" should be useful to anyone who deals with information on small areas of magnetic tape. Cinema Engineering Co., Div. of Aerovox Corp., Burbank, Calif.

Circle No. 54 on reply card



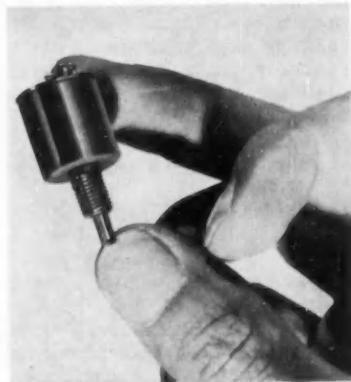
**TINY DIFFERENTIAL** uses ball bearings, weighs 1/3 oz.

Believed to be the smallest in existence is the differential shown above, only 11 in. O.D. Its input shafts are  $\frac{1}{8}$  in. diam. Static friction is overcome by 0.01 oz-in. Pitometer Log Corp., 237 Lafayette St., New York 12, N.Y.

Circle No. 55 on reply card

**UNIVERSAL JOINTS:** A line of new miniature universal joints accepts shafts as small as  $\frac{1}{16}$  in. diam and has maximum outside diameters of as little as  $\frac{1}{8}$  in. Falcon Machine & Tool Co., 209 Concord Turnpike, Cambridge 40, Mass.

Circle No. 56 on reply card

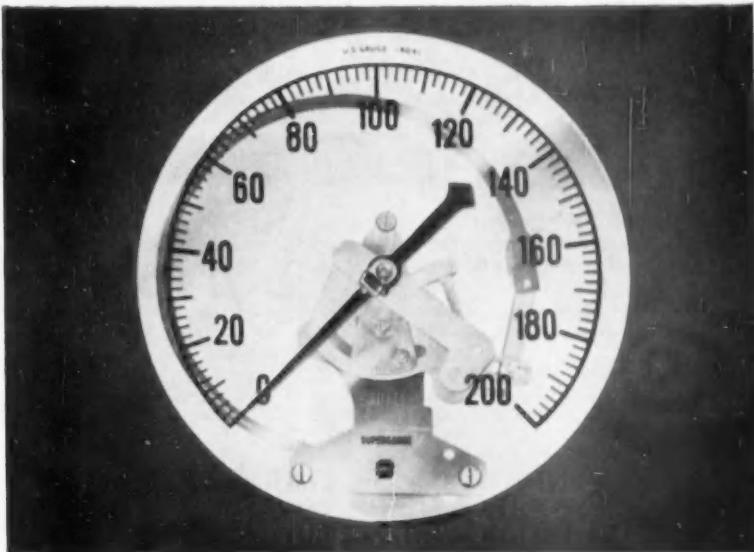


**TINY POT** gangs fourteen deep and weighs 1/2 oz.

Here are the pertinent characteristics of the pot seen above. San Fernando Electric Mfg. Co., San Fernando, Calif.

Resistances... from 5 to 25,000 ohms  
Starting torque ..... 0.75 oz-in.  
Rating ..... 0.3 watts  
Shaft diam .....  $\frac{1}{8}$  in.  
Linearity ..... within 10 per cent  
Rotation ..... 352 deg, electrical  
360 deg, mechanical  
Size ..... 1 in. diam,  $\frac{1}{8}$  in. long

Circle No. 57 on reply card



## New Supergauge Movement Extends Gauge Life; Gives Users Many Extra Benefits

In the quest for longer gauge life under severe operating conditions, one of the principal hurdles confronting instrument engineers has been the problem of gear tooth wear. Many efforts have been made to solve this problem including the use of materials other than metal.

U. S. Gauge research indicated nylon rolling on stainless steel provided the best solution if proper control of the nylon were achieved. All past experience showed that expansion of the nylon when subjected to heat and humidity changed pitch diameter causing binding and wear. This destroyed the gear rolling action, thus defeating its main advantage of assuring longer gauge life under severe operating conditions.

Using a new approach to the problem, U. S. Gauge engineers developed the new \*ARC-LOC movement.

Molded nylon is bonded to the face of the stainless steel segment to maintain pitch diameter. Gear teeth are then accurately generated on the nylon face to assure perfect rolling action on the stainless steel pinion. The segment gear face is broad and all bushings or pivots are deep to assure strength and ruggedness. The result is longer gauge life under severe operating conditions.

Since nylon is applied to the arc of the sector, any tendency of the nylon to grow or shrink occurs along the periphery instead of along the radius. Thus, accurate pitch diameter is maintained and there is no wear from binding. With this design, the smooth gear rolling action between segment and pinion continues even under adverse conditions of heat and humidity.

The new U. S. Gauge ARC-LOC movement also provides several additional features of interest to the user: For easier adjustment the complete movement can be rotated about the pinion axis, positioned properly and locked from the rear. This provides the advantage of linearity adjustment without removing dial and pointer. The unique locking method also eliminates creep during locking.

The Arc-tang segment allows range adjustment without resetting of the pointer.

These added advantages mean savings in time during calibration... an important factor in maintenance reduction.

For complete information on the savings that are made possible by U. S. Gauge's new Supergauges and Solfrunt gauges with the new ARC-LOC movement, write for Publication 1819.

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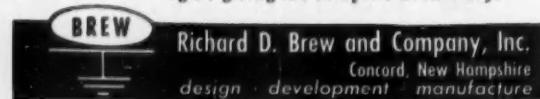
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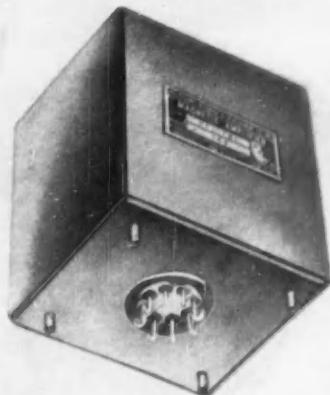
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**Circle No. 58 on reply card**

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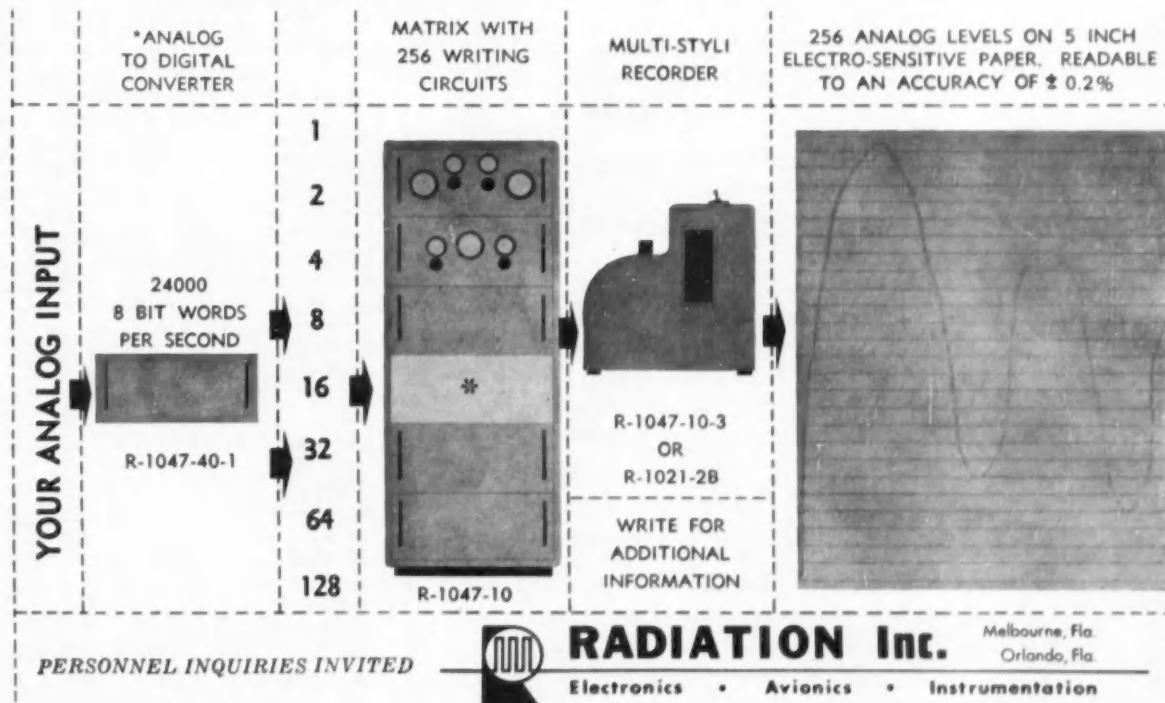
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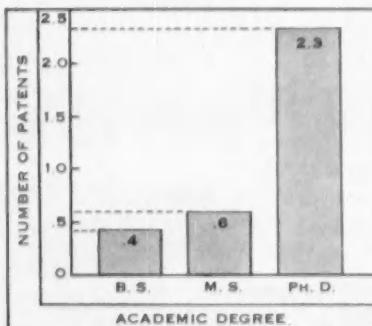




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## ABSTRACTS

### Hydraulic Analogs

From "Hydraulic Analogue Method for Calculation of Thermal Gradients", by Eldon L. Knuth and Emerson L. Kumm, Aerophysics Development Corp. American Rocket Society paper No. 214-55.

The effects of atmospheric heating of the surfaces of high-speed missiles have emphasized the need for studies of the effect of transient temperature distribution through various materials under different conditions. Arbitrary changes in the environment (variation in heat-transfer coefficient and surrounding environment temperature) during an experiment make an analytical solution impractical. Resort to equations using finite differences often results in lengthy iterated calculation procedures or graphical techniques. If, in addition, temperature changes are such that noticeable variation in the material's thermal properties occur with the anticipated change in temperature, then an analog approach to the problem may be necessary.

Many of the difficulties encountered in using hydraulic analog computers in the past have been largely removed through recent availability of the uniform small bore precision tube. Although a number of researchers developed hydraulic analogs of heat flow problems, none has described a simple way to simulate variations in a material's thermal properties with change in temperature. An air flow analog described by M. B. Coyle in the proceedings of the Institute of Mechanical Engineers (England), 1951, took account of changes in a material's thermal properties by step changes in the cross sectional area of air capacitors. The method described in this paper for making changes in capacitor cross-sectional area is simplified from that used by Coyle. Three-dimensional cams are cut according to the desired change in capacitance-versus-pressure and inserted into water tower capacitors.

Also, the analog is extended to allow variations during an experiment in the surface heat transfer coefficient and environment temperature. Extensions are also made to allow the simulation of surface fusion and arbitrary surface heat transfer.

### Its Application

One of the complicating factors in

the study of heat transfer in materials under conditions of forced-convection heat transfer in the presence of very high temperatures is the fact that the temperature through the thickness of the material may vary appreciably. For instance, a 0.5 in. thick wall of low-carbon steel at 1,000 deg F subjected to an environment of 4,000 deg F with forced-convection heat-transfer coefficient of 0.1 Btu/sq ft/sec/deg F might begin to melt its outer surface before the inner surface had appreciably changed temperature. If the melted surface is removed by air forces, then a time-wise step calculation is possible, equating the surface heat flux to the enthalpy change of the melted material. The scope of the application of the hydraulic analog to transient heat transfer is principally to those cases where a relatively large temperature gradient exists in the material undergoing the test conditions with or without surface fusion.

The paper shows the similarity between the equations describing heat flow and fluid flow in the analog. Boundary conditions which occur principally in aerodynamic heating are also considered.

#### How It's Built

Basically, the simulator consists of ten sections of capillary tubing connecting ten water towers (capacitors). The choice of tube diameter (0.101 in.) enables 1 second of heat-flow time to be analogous to 50 sec of fluid-flow time, and 1 in. of heat path to be analogous to 98 in. of liquid path. Different lengths of tubing were cut and connected by valves to allow a wide variety of combinations up to 89 in. of fluid flow.

The recovery-temperature simulator consisted of a liquid-supply system designed to supply liquid at a prescribed head to the boundary-layer simulator. A check of the computer with calculated data indicated that its overall results were accurate to within 5 percent.

#### Surface Fusion

Melting of the wall surface can be approximated in increment fashion by allowing overflow to occur at the height equivalent to melting temperature and removing this overflow to simulate the absorption of the latent heat of fusion. Surface erosion is simulated by using bypass valves to short circuit the hydraulic capacitors and resistors as erosion progresses.

During the computer operation the length of capillary tubing in the boundary layer simulator and the setting of the fluid supply is varied according to a prescribed schedule. The height of the liquid in the ten hydraulic



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## ABSTRACTS

capacitors is read visually and recorded at preselected intervals. When the run is completed, the head readings are converted into temperature values.

### Piping Effects Valves

From "Effects of Adjacent Piping Configurations on Control-Valve Characteristic and Capacity", by G. F. Brockett, Fisher Governor Co., and W. J. L. Kennedy, Stone & Webster Engineering Corp., ASME Paper No. 55-A-138

The care used in specifying control valves in the engineering stages of a project, and the efforts of manufacturers to provide precise valve characteristics and capacities, are often partially nullified by poor installation practices. After sizing, the actual installation layout is then turned over to piping designers, who, in general, give little thought to the control functions of the valve, or to the effect which piping arrangement immediately adjacent to the valve will have on its performance.

The paper is essentially a collection of fifteen graphs showing the change in characteristics of plug valves of various sizes, using air and water, when operated at different pressures and pressure drops in association with reducers, plug cocks, elbows, etc.

### Test Conditions

In the test results, the basic capacity of the control valve is plotted for reference. It is common practice to include the pressure drop across the entire control-valve manifold under the pressure differential available for control. That is, if 10 psi drop is allowed for control, 2 psi of this may be used in the piping immediately adjacent to the control valve. The authors have followed this practice in the test results; the control valve and its adjacent piping were considered a system and treated as a unit in assigning pressure drop and calculating flow.

It's obvious that a reduction in effective capacity of the control valve results, but this does not insure that these effects will be compensated for. If it were not true that many control valves are oversized by duplication of safety factors, this effect would be more commonly noticed.

Although the valve capacity decrease is predictable, the effect of adjacent piping on valve characteristics is not obvious and is shown to vary considerably.

## NEW BOOKS

T. J. Higgins reviews  
a process control book . . .

AN INTRODUCTION TO PROCESS CONTROL SYSTEM DESIGN. By A. J. Young, Head of the Central Instrument Laboratory, Imperial Chemical Industries Limited. 379 pp. Published by Longmans, Green and Co. Ltd., London, England. 42 shillings. Available in U.S. from Longmans, Green, New York City.

In the reviewer's opinion, this is the best book on process control theory and design which has been written in English. It joins basic feedback control theory with empirical knowledge gained from operating experience to make a coherent whole. It is written by an engineer with a comprehensive grasp of modern control theory, and an extensive acquaintance with current unit design techniques. This book fills a long-standing need of America and British instrumentation and process control engineers—it is in English, is up-to-date, and uses only simple analysis.

In his preface the author states his belief "that a simpler, almost non-mathematical, treatment of the basic principles of process control using the frequency response approach will be welcomed by many who wish to amplify their practical experience and by . . . newcomers to the field . . .".

The first of 19 chapters, "Economics", outlines the economic grounds underlying choice of the type of control for the plant. Chapters 2, "The Closed Loop" and 3, "Plant Characteristics" explain the essential differences between open and closed-loop control and illustrate, with examples, the basic plant features which enter into analysis. Chapters 4, "Systems of Exponential Transfer Stages" and 5, "Plant Controllability" explain in detail the analytic treatment of a cascaded series of single-lag stages.

The frequency-response approach was chosen as the basic method of analysis because it permits basic understanding with simpler mathematics than other techniques. Accordingly, Chapters 6, "The Frequency Response of a Plant" and 7, "Experimental Frequency Response Analysis" advance the basic theory and experimental techniques evolved by the author and his colleagues for determining the frequency response characteristics of plant components.

To predetermine the control be-

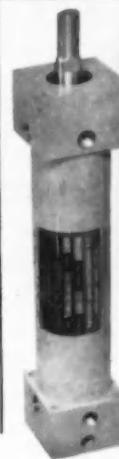
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**NEW BOOKS**

havior of a plant, controller frequency response must be known also. Thus Chapter 8, "Characteristics of Theoretical Controllers", describes the frequency characteristics of idealized controllers of proportional, integral, derivative and compounded nature. Chapter 9, "The Operation of a Continuous Control System", discusses the combined characteristics of plant and controller in closed-loop operation.

Chapter 10, "Prediction of Controller Settings, Control Quality and Plant Controllability" is somewhat subsidiary. Its prime object is to demonstrate that the control quality for a given controller hinges, essentially, on the characteristics of the plant.

Subsequent chapters consider (11), "The Basic Principles of Pneumatic Controllers"; (12) "Some Three-Action Pneumatic Controllers"; (13), "Electric, Electric-Pneumatic, and Hydraulic Controllers".

Chapter 14, "Measuring and Transmission Lags", describes the character and influence of phase lags and attenuations of auxiliary components of the closed-loop system. In Chapter 15, "Transfer Stages", the frequency response characteristics of various types of transfer stages in the plant are considered as compounded of simple lag stages. Lumped and distributed-parameter stages, independent and interacting, are discussed at length and illustrated by examples.

Next, in Chapter 16, "Valve Characteristics", the commonly-used corrective control valve is discussed in general terms as an important element of a control system. It is shown by example that satisfactory control quality often hinges on a proper choice of this element.

The text is closed out by Chapters 17, "The Effect of Disturbance", a consideration of the effects on plant performance of an undesired disturbing signal acting at an arbitrary point in the system; 18, "Complex Control Systems", being an introduction to multiple-loop systems; and finally 19, "System Design", summarizing the principles discussed in preceding chapters and describing a somewhat personalized technique for designing a process control system based on these principles.

There are 6 appendices: the first on differences of terminology in various countries.

Thomas J. Higgins  
Professor of Electrical Engineering  
University of Wisconsin

## Printed Circuits

PROCEEDINGS OF THE SYMPOSIUM ON PRINTED CIRCUITS. 122 pp. Published by Engineering Publishers, GPO Box 1151, New York 1, N. Y. \$5.00

This book contains, in complete form, the technical papers presented at the 1955 Symposium on Printed Circuits, which was sponsored by the Engineering Department of Radio-Electronics-Television Manufacturers Association with the participation of the Professional Group on Production Techniques of the IRE. The pertinent questions and answers that followed the presentation of each paper are included.

The papers cover both theory and practice—materials, components, design and production, testing and evaluation, and reliability and management problems. All the methods of printed circuitry currently in commercial use are discussed. There are case studies of their use in reducing manufacturing costs.

## Mechanisms by the Carload

MECHANISM. Joseph Stiles Beggs, Hughes Aircraft Co. 6½ by 9½ in., 418 pp. Published by McGraw-Hill Book Co., New York City.

While some attempt is made in this book to carry out a continuing line of thought, it remains basically a detailed examination of a wide variety of mechanisms, each pretty much standing on its own. The basis of a course in advanced kinematics at UCLA, it begins with a discussion of the required mathematical tools needed to thoroughly analyze complex mechanical systems, but with the start of the third chapter introduces the reader to basic facts about a wide variety of specific devices. Gears of every description, and mechanisms associated with them, plus information on their manufacture, comprise the bulk of the third chapter. Next come cams, rotary drives, linkages, tension and flexural links, compression links (including fluids), computing mechanisms (mechanical calculators and electromechanical analog computer components), control mechanisms (this tends to be a rather weak section), a fact-packed chapter on Newtonian mechanics, and the usual compendium of interesting gimmicks.

Partially because of the unusual number of diagrams and photos (most of them excellent) this book is a truly interesting one to thumb through. It avoids the obvious and does a thorough job on the complex gadgets that demand dynamic analysis.



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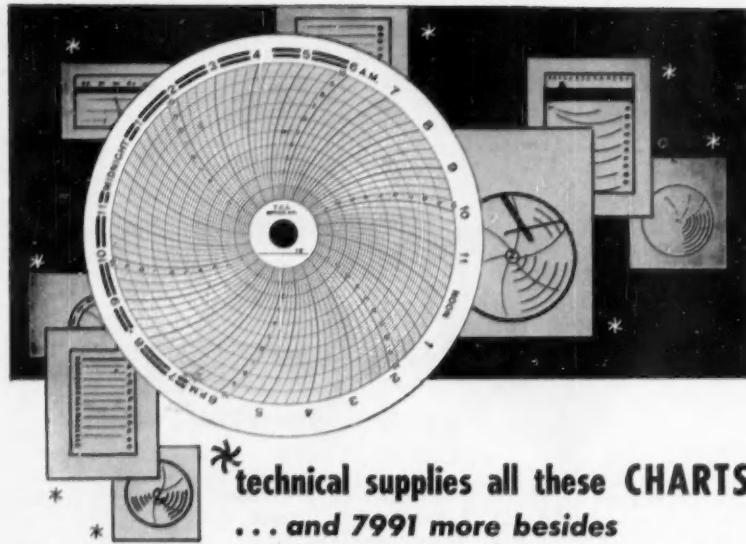
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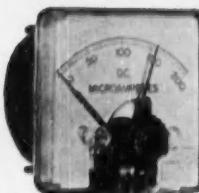
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The trip point is adjustable to any point on the scale arc.



TYPE 306  
STEP  
MOTOR

SUPPLY

#### SIZE 18 STEP TRANSMITTER

An inexpensive combination to replace costly servos and synchros in many applications requiring remote indication or positioning.

A reversible d.c. motor keeps in step with a low torque transmitter. Torque amplification of 30:1 is obtainable without electronic amplifier. Several motors may be driven synchronously from same transmitter without reflecting torque to transmitter.

#### TYPE 306 STEP MOTOR

|                 |                   |
|-----------------|-------------------|
| Voltage         | 115 d.c.          |
| Stall Torque    | 20 oz-in.         |
| Max. Speed      | 150 r.p.m.        |
| Size            | 3" Dia. x 3" long |
| Step Increments | 15%               |

#### SIZE 18 STEP TRANSMITTER

|        |                       |
|--------|-----------------------|
| Torque | 0.2 oz-in.            |
| Size   | 1-1/4" Dia. x 3" long |

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## DECEMBER

American Chemical Society, 1955 Christmas Symposium on Process Instrumentation and Control, Princeton University, Princeton, N. J. Dec. 29-30

## JANUARY

National Simulation Conference, Institute of Radio Engineers, Dallas-Fort Worth Chapter (Professional Group on Electronic Computers), Hotel Baker, Dallas, Texas.

Jan. 19-21

American Institute of Electrical Engineers, Winter General Meeting, Statler Hotel, New York.

Jan. 30-Feb. 3

## FEBRUARY

Institute of Radio Engineers, Eighth Annual Southwestern Conference and Electronics Show, Municipal Auditorium, Oklahoma City, Okla. Feb. 9-11

Louisiana State University, 1956 Conference on High-Speed Computers, Baton Rouge, La. Feb. 15-17

## MARCH

Institute of Radio Engineers, National Convention, Kingsbridge Armory and Waldorf-Astoria Hotel, New York. Mar. 19-22

American Society of Mechanical Engineers, Instruments and Regulators Div., Second Divisional Conference, Princeton University, Princeton, N. J. Mar. 26-27

## APRIL

Special Technical Conference on Magnetic Amplifiers, sponsored by American Institute of Electrical Engineers, Institute of Radio Engineers, Instrument Society of America, Hotel Syracuse, Syracuse, N. Y. Apr. 5-6

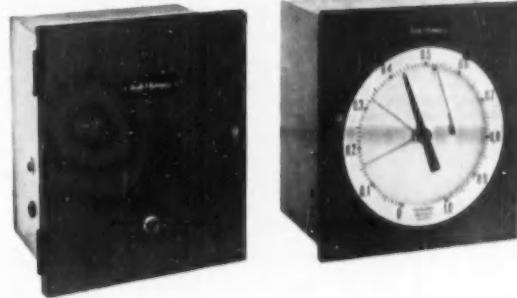
American Institute of Electrical Engineers, Conference on Recording and Controlling Instruments, Bradford Hotel, Boston. Apr. 26-27

## MAY

American Society for Testing Materials, Fourth Conference on Mass Spectrometry, Netherlands Plaza Hotel, Cincinnati, Ohio. May 27

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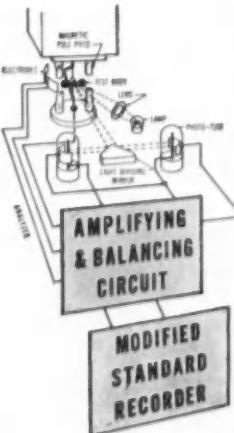
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1. To locate those of the nation's young men and young women who are best equipped to go to college.
2. When necessary, to help these young people go to college by giving them financial aid.
3. To help colleges and universities meet the full cost of the instruction of those to whom National Merit scholarships are granted.

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school graduates do not go to college. The principal reason is that they do not have the money required.

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## Two For One Return Offered

However, there are numerous other inducements to business firms to finance National Merit scholarships. These scholarships may:

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3. Be limited to a college course, such as science, engineering or liberal arts, of special concern to the sponsor.
4. Be restricted to candidates or institutions in geographic areas specified by the sponsor.

In addition to these advantages there is a special financial inducement to help the Merit Scholarship program. It is that for every Merit scholarship a firm or individual finances, the Corporation will, up to the limit of \$8 million, match the funds and make another National Merit scholarship available.

There are many good ways of helping our financially beleaguered colleges and universities, and many corporations are already using one or more of them.\* For those companies that can do so without embarrassing complications one of the best ways is to make unrestricted gifts directly to the institutions. But this new way provided by the creation of the National Merit Scholarship Corporation (Address: 1580 Sherman Avenue, Evanston, Illinois) has the broad appeal of serving two purposes of transcendent importance simultaneously. The purposes are to see that our best brains are fully trained and utilized and that our colleges and universities, crucial contributors to this process, are helped at the same time. Business will serve the nation and its own community well by giving the National Merit Scholarship Corporation generous help.

\* These, as well as the plight of our colleges and universities, are discussed in a pamphlet, "Business Aid to Our Colleges and Universities," which embodies a series of five editorials which appeared in all McGraw-Hill publications. Copies of the pamphlet can be obtained without charge by addressing the Department of Economics, McGraw-Hill Publishing Company, Inc., 330 West 42nd Street, New York 36, New York.

Methods of helping our colleges and universities financially are also outlined and discussed in a pamphlet, "Aids to Corporate Support of Higher Education," which may be obtained without cost by addressing the Council for Financial Aid to Education, 6 East 45th Street, New York 17, New York.

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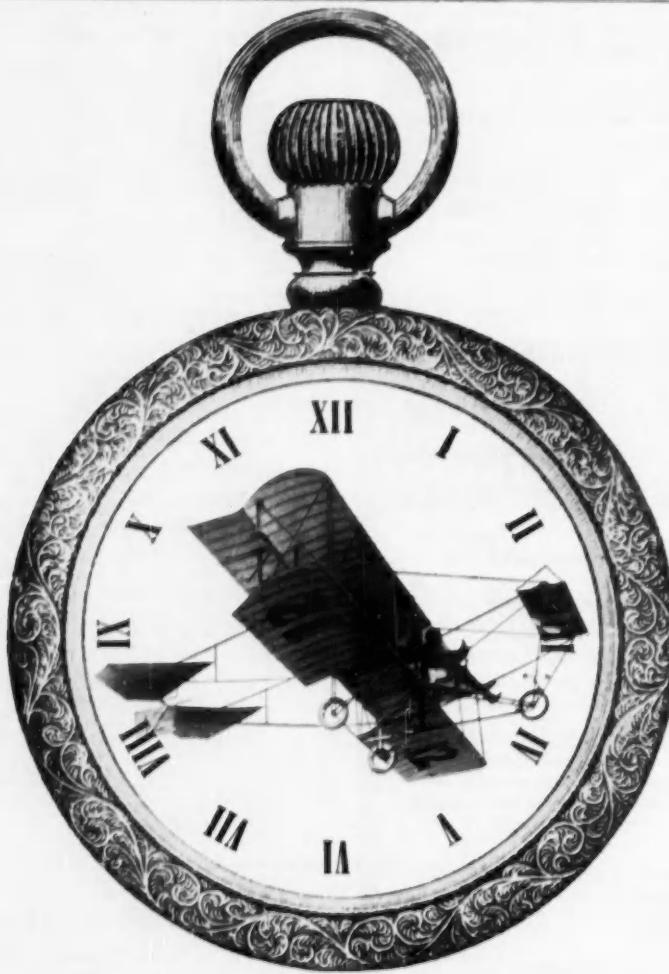
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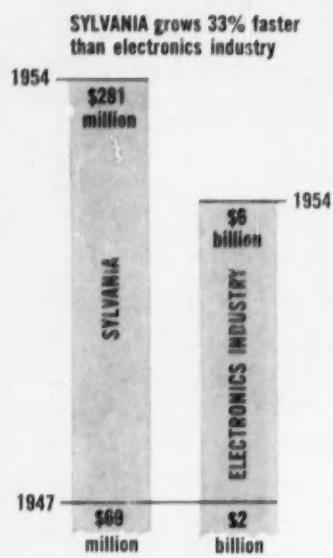
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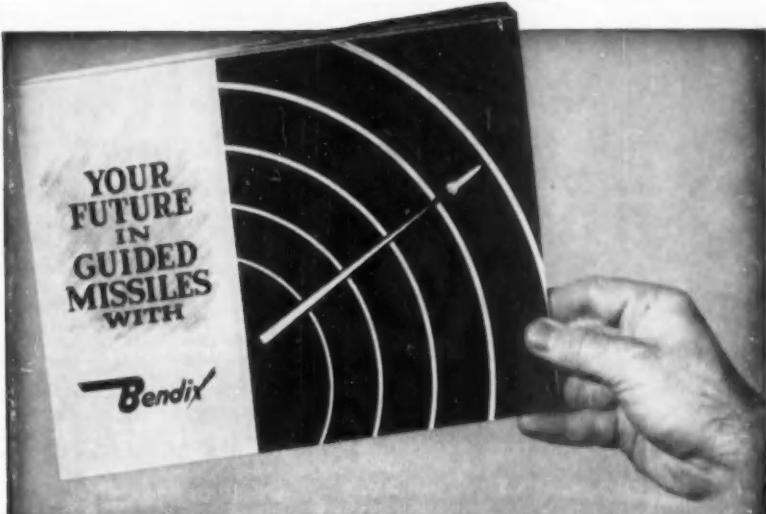
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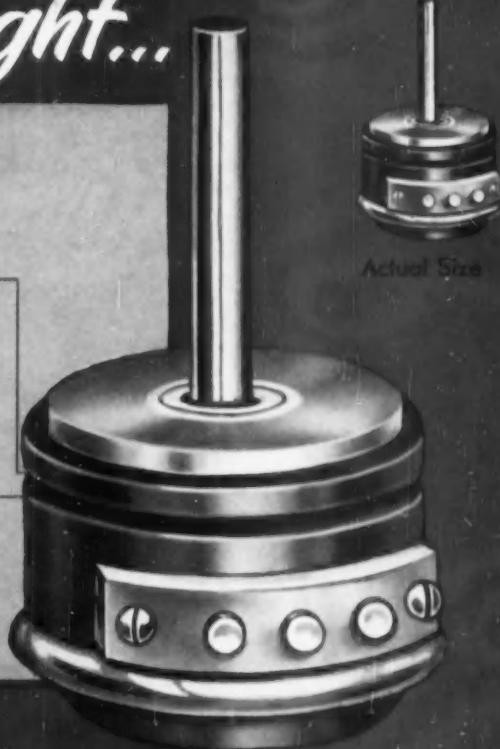
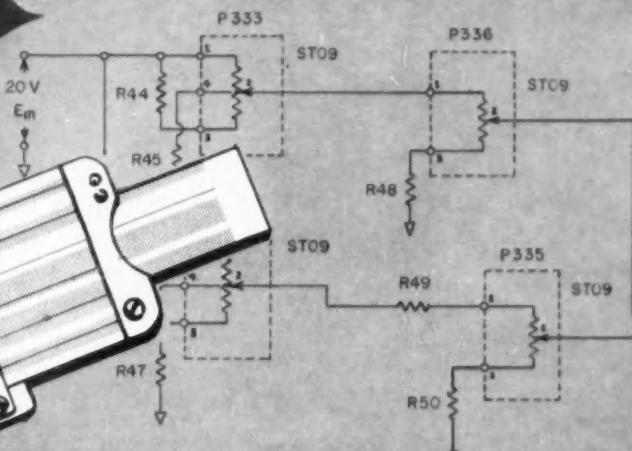
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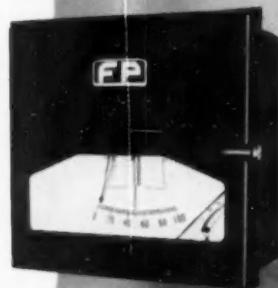
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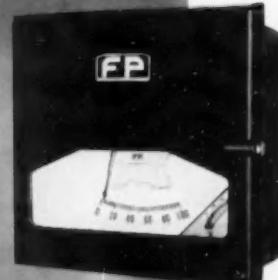
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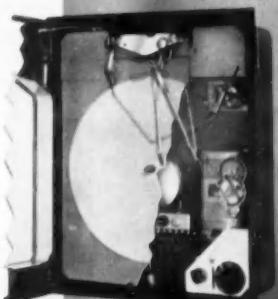
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